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Understanding the Aeromedical Patient Journey and Outcomes in Central Queensland: A Linked Data Study

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Thesis submitted for the degree of Doctor of Philosophy

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I acknowledge the Traditional Owners of the land which has been the focus of my research, the Darumbal people in the region of Central Queensland and pay my respects to Elders past, present and emerging. I recognise their connection to Country and their role in caring for and maintaining Country over thousands of years. May their strength and wisdom be with us today.

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Ethics Statement

This research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research 2007 and The Declaration of Helsinki, incorporating the principals of informed consent, right to withdraw, privacy and confidentiality.

- Central Queensland Health and Hospital HREC (CQC/16/HREC/8) (Study 2 and 3) and (CQC/16/HREC/5) (Study 4)
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I agree that the above statements about my respective contributions to authorship are true.

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Abstract

Introduction

Air ambulance services provide medical care and transportation to sick and injured people. Future sustainability of air ambulance services depends on a strategic health service plan, which defines how quality care provision will be measured. However, defining quality is a complex construct, and measuring the quality of patient care and service performance is challenging due to the effects of care provided before and after aeromedical flight, as well as the general nature of emergency medical provision, often including high patient acuity, limited resources, and heterogeneity of healthcare access.

Objectives

This thesis explores aeromedical patients' journeys in the Central Queensland Hospital and Health Service (CQHHS) region to investigate patient and service outcomes and develop a framework for evaluating service quality. Achieving this aim requires linkage between aeromedical data and data from the sending and receiving health facilities, as until now linked data has not previously been available. The overall objective of this study is to explore the performance of a regional aeromedical system to inform the development of a performance evaluation framework for aeromedical services. The four operational aims of the thesis are:

1) To document the range and nature of aeromedical outcome measures in the literature

2) To use the results of aim 1 to develop an aeromedical quality framework and use it for reporting existing aeromedical patient and service outcomes

3) To explore aeromedical patients' journeys in Central Queensland using linked data

4) To describe rural clinicians' perceptions of the supports and barriers they experience as they request aeromedical retrieval for patients with suspected appendicitis in Central Queensland.

Methods

The research program included four studies:

Study 1 was a scoping review of the literature to capture outcomes measures used to evaluate aeromedical services and to construct a draft performance evaluation framework.

Study 2 is a quantitative analysis of a regional aeromedical service which included two analyses:

- Analysis of a linked data set which included aeromedical, emergency department (ED), hospital, and mortality data to explore patient and service outcomes.
- A description of 13,977 aeromedical tasks to evaluate the system performance.

Study 3 used suspected appendicitis as a case series to further explore patient outcomes and thus system performance.

Study 4 was a qualitative composition involving forty-four interviews with clinicians to explore their view of the factors influencing system performance.

Results

In Study 1, a scoping review examining air ambulance outcome measures from eighteen relevant articles revealed eight main themes: asset/team type, access to definitive interventions, prehospital factors, mortality, morbidity, responsiveness of service, accessibility of service, and patient disposition. Also identified were seven additional areas needing performance evaluation: patient comfort and satisfaction, cultural awareness, safety alarms to identify volume stress, coordination of resources, cost of service, total system response time, and an overall evaluation of the patient journey. The aeromedical quality framework was created based on the six quality domains from the Institutes of Medicine (effective, efficient, safe, patient-centered, timely, and equitable) and the three quality domains from Dr. Donabedian (structure, process, and outcome). The framework's form and function is able to be used by other aeromedical services.

Study 2, quantitative aeromedical-only data, reported the results of 11,456 tasks in the CQHHS region. Males comprised 59% of the patient population. Adult patients (aged 18 years and older) were more common than pediatric patients, comprising 86% of the study total. Fixed-wing aircraft were used in 87% of the flights, compared to 13% rotor-wing. Response priority category 4 (less urgent) was the most common, comprising 42% of patients.

Study 2 also included a quantitative linked data study which reported the results of 13,977 episodes of care. Data sources for each episode included the Royal Flying Doctor Service (RFDS), LifeFlight Retrieval Medicine (LRM), emergency departments, hospitals, and the death registry. Three regional referral pathways were identified based on sending and receiving locations: 'Intraregional', 'OUT of region', and 'INTO region'. There were 10,864 total patients in the study, of which 2,289 patients (21%) had multiple flights. Of these multiple flights, 675 were during the same episode of care, either towards definitive care (12%) or back-transfers (88%).

Study 3 was based on the finding from study 2 that the most frequent patient pathology type from sending and receiving EDs in two of the three referral pathways in CQHHS (Intraregional and 'INTO region') was appendicitis. Study 3 explored the patient outcomes of these appendicitis patients. This quantitative study reported the results of 684 episodes of patients with suspected appendicitis and/or acute abdominal pain in three referral progression pathways based on the sending and receiving hospitals' capability levels. In total, 5.6% patients were discharged from ED. 83.3% of all rural origins entered via the ED, compared to direct hospital admission. Overall, 3.8% of all appendicitis patients were triaged to tertiary hospitals rather than regional-level hospitals. Severe appendectomies were less likely to have longer request-to-activation wait times and had longer lengths of stay than minor complexity appendectomies.

In Study 4, I presented a qualitative study showing the results of forty-four rural sending-facility clinician interviews. The majority of participants identified strong and effective teamwork of rural nurses and doctors as a support structure. The decision-making process to request aeromedical retrieval was a shared, joint process, and clinicians identified a supportive collegial culture which supported asking questions without the expectation of anyone having all the answers. Perceived barriers facing these sending clinicians were receiving clinicians' lack of understanding of rural hospital resource limitations, and a lack of patient data connectivity.

Conclusion

This thesis explored the aeromedical patient journey and aeromedical service outcomes using data linkage and rural clinicians' reports of their experiences when requesting aeromedical services. The data linkage match rates were improved by the study's inclusion of data from LRM and RFDS. The aeromedical quality framework was found to be a useful tool to assist aeromedical providers, planners, and payers to report patient and service outcomes, which will help future decision-making and planning. This is important to produce more accurate evidence for decisions of health resource allocations within the hospital regions and across the health system. The next steps for this body of work includes applying the framework and data linkage state-wide, to enable more efficient and effective delivery of aeromedical services in Queensland.

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List of acronyms and abbreviations

Acronym	Phrase
ANOVA	Analysis of Variance
ARIA+	Accessibility/Remoteness Index of Australia
AR-DRG	Australian diagnosis-related groups
ATS	Australian Triage Scale
BSN	Bachelor Science in Nursing
CCRIS	Clinical Coordination and Retrieval Information Systems
COREQ	Consolidated Criteria for Reporting Qualitative Research
CQHHS	Central Queensland Hospital and Health Service
CT	Computed Tomography
ED	Emergency Department
EDIS	Emergency Department Information System
FW	Fixed wing aircraft
ICD-10-AM	International Classification of Diseases, Australian Modification, tenth revision
IOM	Institutes of Medicine
IQR	Interquartile Range
JCU	James Cook University
LRM	LifeFlight Retrieval Medicine
MSN	Master Science in Nursing
n.p.	not presented
NUM	Nurse Unit Manager
PHA	Public Health Act
PI	Primary Investigator
QHAPDC	Queensland Hospital Admitted Patient Data Collection
QLD	Queensland
QNETS	Queensland Neonatal Emergency Transportation Systems
RFDS	Royal Flying Doctor Service
RN	Registered Nurse
RSQ	Retreival Services Queensland
RW	Rotor wing aircraft
sd	standard deviation
SSB	Statistical Services Branch
STROBE	Strengthening the reporting of observational studies in epidemiology
X^2	Chi square

Glossary of Terms

Access to care: "The opportunity to identify healthcare needs, to seek healthcare services, to reach, to obtain or use healthcare services to actually have the need for services fulfilled"[1].

Aeromedical back transfer: patient flight from higher level of care to lower level of care. Other terms include: step-down transfer or back load transfer.

Aeromedical base: building/ hanger location where airplanes/ helicopters/ vehicles conducting patient transports originate and return.

Delay in care: barriers that limit or prolong 'access of care' (e.g., asset or hospital capacity and availability, weather, technical or diagnostic equipment, decision-making or communication)[1].

Effective: providing evidence based care to all who could benefit and refraining from providing services to those not likely to benefit[2].

Efficient: avoiding waste, including equipment, supplies, ideas or energy[2].

Equitable: care that does not vary according to gender, ethnicity, geographic location or socioeconomic status [2].

Health Indicator: Metric put in context, usually using a ratio (per X) and is designed to ensure comparability (e.g., standardized or risk-adjusted). Directionality may or may not exist[3],

Impact measure: "A measures of the direct or indirect effect or consequence resulting from achieving program goals"[4].

Input measure: "A measure of the resources used to achieve an outcome (e.g., employees, funding, etc.)"[4].

Outcome measure: "An assessment of the results of a program compared to its intended purpose"[4].

Output measure: "A tabulation, calculation, or recording of an activity or effort that can be expressed in a quantitative or qualitative manner"[4].

Outcome Measure (Donabedian): the effect of care and its impact on the health status of patients and populations[5].

Overtriage: utilisation of a resource to those that may not benefit[6].

Patient-centered: respectful and responsive to patient preferences, needs and values[2].

Patient outcome measure: "a health state of a patient resulting from health care" (e.g. physiologic measures, radiology and lab results and morbidity)[7].

Performance Indicator: A health indicator that has a desired direction[3].

Process measure: a health care-related activity performed for, on behalf of, or by a patient (e.g. readmission rates or discharge status)[7].

Process Measure: how health care is given and received as guided by policy, standards and procedures[5].

Safe: avoiding injury[2].

Secondary overtriage: transferred patients receiving health services at tertiary facilities which bypassed capable and available regional-level hospitals[8].

Structure Measure: material resources; facilities, equipment, human resources (e.g., number of personnel and their qualifications), and organizational structures (e.g., funding and reimbursement)[5].

Timely: reducing waiting and delays for those that give and receive care [2].

Undertriage: not utilising a resource to those that could benefit[6].

Utilization: realized access[1].

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Author's definitions created for thesis

Adaptive Referral System (ARS): incorporates the linear emergency care system (one-way toward higher levels of definitive care) and expands it to include the 'reverse flow'; those patients and resources which are going back to a lower level of care but involve the emergency care system.

Aeromedical admission pathway: after an aeromedical flight, admission to a healthcare facility via the emergency department or the direct admission to the hospital.

Aeromedical escalating task (multi-sequence): More than one flight; each to higher levels of care without a separation in care (e.g., rural hospital-to-regional hospital-to-tertiary hospital).

Aeromedical patients' journeys: the integrated, continuum of care that spans multiple settings; prehospital and hospital based pre-flight, flight transport, after flight hospital inpatient and disposition.

Aeromedical referral progression pathways: the pattern of change in the patients' level of care (e.g., rural hospital-to-regional hospital, rural hospital-to-tertiary hospital, regional hospital-to-tertiary hospital, or tertiary hospital-to-regional hospital).

Aeromedical regional referral pathways: referral of patients toward appropriate levels of care in pathways in reference to the hospital service region (e.g., intraregional, into region, out of region).

Aeromedical quality framework: the assessment tool, developed as a balanced dashboard using Institutes of Medicine and Donabedian quality frameworks.

Comprehensive Patient Journey Time (CPJT): will calculate air ambulance total system response time (activation-to-handover at receiving facility) and complete utilisation of healthcare services; ED admission through hospital discharge, will add a layer of under-standing to their journey.

Multiple flights per person: number of times one patient used the service, during the study period.

Pre-threshold alarms: upward utility trends in regional referral patterns that may indicate volume stress and put pressure on safe, appropriate, early intervention and transfers.

Task time gap: a reasonable, estimated task time in the given context.

Teamwork in remote locations: rural hospital work culture of safe and effective communication among peers.

Preface

Terminology

The term aeromedical is synonymous with air ambulance and air medical. These terms refer to a specialised, dedicated air craft for medical purposes. These include both helicopter and fixed-wing aircraft.

Motivation and personal background

I have worked as an intensive care unit nurse in some of the largest tertiary hospitals in Denver, Colorado America, at a time when air ambulance services were abundant and frequently utilized. When I moved to Australia, I was astounded to learn of the significant distances that some patients were required to fly to receive definitive care. Even more surprising to learn that some patients fly for diagnostic confirmation to rule-in or rule-out suspected pathology. My research question began to take shape from one, key conversation with the (then) air ambulance medical director, when I asked, “What is one thing you want to know about aeromedical patient outcomes?” Her reply was, “I just want to know who dies.” These seven words changed the trajectory of my nursing career as I began to learn that information, along the aeromedical patients’ journeys, was contained in separate data files and not yet linked. Consequently, the cohort of aeromedical patients’ outcome was unknown. This awareness set me on a path to explore that question and to seek answers.

Chapter 1. Introduction

Overview of this chapter

This chapter provides background of the role of air ambulances and their history, and situates this research within the rural, remote, and regional community context in Central Queensland. This chapter provides an overview of the thesis, examines the current challenges in measuring the quality of aeromedical service provision and the rationale for linking aeromedical patient and service data to enhance coordination of care. The final portion of this chapter describes the significance of the work and outlines the research question, aims, and objectives.

1.1 The role of air ambulances

Aeromedical retrieval is a health service comprised of highly skilled and experienced doctors, nurses, and paramedics with specialised resources which allow for patient assessment, intervention, and transportation[1]. The term 'air ambulance' has three synonymous terms generally used in the literature: aeromedical, air medical, or aeromedical retrieval. For the purpose of this thesis, all of these terms will be used interchangeably to reflect the inclusion of both helicopter and fixed-wing aircraft. Helicopter Emergency Medical Service (HEMS) will not be used in general terms unless discussing exclusive utilisation of helicopter-only tasks.

Air ambulance services provide medical care and transportation to sick and injured people, and help improve patient outcomes in three aspects of their service: rapid response, specialised interventions, and patient-focused multi-disciplinary team integration.

Firstly, rapid response is the hallmark of aeromedical retrieval[2]. Patient outcomes can be improved by decreasing the time interval from onset of symptoms to definitive intervention[3-6]. In urban-dense settings like London, helicopters are able to bypass vehicle and pedestrian traffic to quickly reach patients[7]. In rural and remote locations with significant distances between healthcare facilities, fixed-wing aircraft are generally able to transport patients faster than ground vehicles, and also avoid natural barriers like flooded roads or bushfires.

Secondly, the aeromedical service provides specialised, highly-skilled teams able to perform advanced clinical interventions which improve patient outcomes. In general, air ambulance teams are clinical professionals with complimentary scopes of practices and training, such as nurses, doctors, and paramedics[8]. Staffing models may include these combinations, depending on patient needs and service configurations: two nurses, a nurse and a paramedic, a paramedic and a doctor, or a nurse and a doctor[8]. Highly specialised transport teams are able perform clinical procedures and have resources at their disposal that are typically used in emergency department resuscitation or intensive care units such as extracorporeal membrane oxygenation (ECMO) (i.e., a machine that acts as a patient's heart and lungs, similar to heart-lung bypass used during open-heart surgery)[9]. Additionally, retrieval clinicians may provide assistance and support for rural and remote clinicians in the event of limited rural hospital resources or training, for instance in the case of rapid sequence intubation which requires specific medication and ongoing mechanical ventilation[9]. The scope of services and intervention capabilities available through aeromedical services can vary by region both in Australia and internationally. Complimentary aeromedical service interventions may also include search and rescue, disaster response and management, and international repatriation. These unique aspects of air ambulance interventions function to improve patient outcomes. Further details of clinician skill mix and training will be discussed in section 1.8.3.

Finally, air ambulance services consist of patient-focused multi-disciplinary teams which help to improve patient outcomes. The patient-focused team approach has four layers:

1) multi-professional teams (e.g., aviation, clinical, communication, and engineering), 2) multi-discipline teams (e.g., nursing, medical, and paramedicine), 3) multi-role teams (e.g., clinical coordination and transport coordination) and 4) multi-facility teams (e.g., sending facility teams and receiving facility teams). These high-performance teams function by placing the patient at the centre of activity, thereby strengthening the overall care being provided and improving patient outcomes[10].

These three aspects of an advanced medical and aviation service help to improve patient outcomes[10]. However, the current drive to advance medical and aviation capability may have unintended consequences. For instance, the future sustainability of the service may reach a tipping point (i.e., a series of small improvements which becomes significant, causing a greater change that is no longer sustainable), without a strategic health service plan which identifies and evaluates performance indicators[1].

1.2 Measuring quality service provision

The World Health Organization (WHO), the Australian Medical Association (AMA) and the Queensland Department of Health (QDH), state that the future sustainability of healthcare services will depend how quality care is defined and measured[12-14]; you can't improve what you can't define or measure[15]. However, defining quality is a highly complex endevour[16,17], and finding a metric or element to measure quality is equally complex[18]. The pathway to quality must begin with accurate, reliable, and valid measurement of health service performance[19].

While no performance measure is without flaw, once the challenges have been identified, developing consensus and standards can occur. Developing a set of standards is an opportunity for air ambulances to measure quality care and improve patient outcomes[20]. Ensuring consistent specific quality measurements reduces duplication, inconsistencies, and gaps in performance, and eliminates metric 'cherry picking' which highlights stakeholder self-interests[20]. Failure to establish consistent meaningful and valid performance measures hinders the ability to recognize disparity and variations of care[20-22]. Dr. Avedis Donabedian, a founder of medical outcomes research[23], heeded a warning in a landmark paper in 1966 regarding the certainty of assessing health service quality, as it's often bound by contemporary strengths and limitations of clinical science. Outcomes are influenced by multiple factors, including the antecedent processes of care[23]. Consequently, the quality measure of aeromedical performance may reflect the interconnectedness (i.e., events antecedent and subsequent of aeromedical flight) of the health system, and not the result of the retrieval service quality per se[24].

1.3 Current challenges in measuring air ambulance service provision

Currently, there are five challenges in measuring quality performance of an aeromedical service (further discussed below in sections 1.3.1-1.3.5). The first two facets relate to events antecedent and subsequent to aeromedical flight and the last three relate to the general nature of the emergency medical system: 1) ED/ hospital access blocks, 2) time delays due to ground transport/aviation logistics, 3) the allocation of limited resources, 4) high patient acuity and multiple co-morbidities, and 5) significant heterogeneity among air ambulance systems.

1.3.1 ED/ hospital access block

Aeromedical interhospital transfer (IHT) moves patients from one ED or hospital unit to another ED or hospital unit. Patient assessment and processing problems such as ED access blockages may impact the air ambulance service efficiency and patient outcomes, as the patient becomes sicker with longer delays. According to the Australian College for Emergency Medicine (ACEM), access blocks occur when available resources and inpatient hospital capacity can no longer to meet service demand, such as when EDs become crowded[25]. Specifically, elective surgery levels and hospital occupancy are strongly impacted by ED overcrowding[25]. Throughout Australia, the demand for IHTs and ED usage requiring hospital admission has increased 25% from 2012 to 2019[25]. The problems associated with ED overcrowding and access blocks continue to grow.

Emergency Department access blockages are correlated with poor patient outcomes[26-28], notably in delays to patients accessing definitive treatment. In a recent study, patients with ST segment elevation myocardial infarct (STEMI) who were directly admitted to interventional cardiology had decreased mortality when compared with patients that were first admitted via the ED[29]. Specifically, the time between chest pain and opening the cardiac vessels was the most impacted by patients that entered via the ED, with longer delays compared to those directly admitted to interventional cardiology[29]. Further evidence of critical access block and its impact on patient outcomes was shared by the Australian Medical Association (AMA) on 27 April 2021: "Queensland doctors say public hospitals are at crisis point, with clogged Emergency Departments, too few beds and an exodus of burnt-out staff"[30]. Australian Medical Association Professor Chris Perry OAM stated, "Before we prise open Treasury's purse, we need to know how hospital beds are being used and who is using them. People would die if the access block was not fixed."[30]. Currently, there is limited understanding of how hospital beds are being used by interhospital transfer patients (both origin and destination) in Central Queensland.

A study conducted in Perth, Western Australia, found 23% of ED-ED ground transfers experienced access block[26]. However, the author found that the rates of mortality for those IHT where access was blocked were actually lower (35%) than those not blocked[26]. The author attributed this to the receiving hospitals' preparation and expectation for the IHT and also the lower urgency of patients who experienced access block. Future solutions to minimize delays due to access block involve improved hospital efficiency as a whole[25].

Queensland Health (QH) (the State's public health provider) has recognised access block problems and committed to a state-wide initiative to find solutions to efficient and equitable emergency service delivery[31]. QH stated its commitment in 'A Whole of Hospital Approach' for "reviewing and optimising the patient journey through the entire acute hospital experience and back into the community."[31] (p. 4). In the same initiative, QH identified that "existing processes for interhospital transfers result in the inappropriate use of ED's"[31] (pg. 5). Therefore, a whole-of-system approach to access block includes change across the entire health system, with the identification of clinical flow solutions that are tailored to community needs. This should involve a detailed exploration of the patient journey through the hospital, including how and why they arrived at the ED (i.e., input), how they travelled through the various hospital departments (i.e., throughput), how they were discharged from the hospital (i.e., output), and what factors are preventing timely and clinically appropriate events throughout the patient journey[25,32].

QH developed a protocol to identify clinical flow solutions for IHT. The protocol indicates direct hospital admission for stable patients unless they have "an undifferentiated condition requiring specific investigations or have deteriorated in-transit, necessitating ED intervention"[33]. Alternative flow patterns are necessary in light of increasing ED volumes and longer wait times due to access block[34]. A recent study found that increasing direct admission to hospitals may be an alternative which will decrease ED volumes[34]. These findings are encouraging, but further exploration in direct hospital admission for IHT's are necessary to guide policy. Until future research can shed light on direct hospital admission patterns, measuring the quality performance of an aeromedical service is challenged due to increasing ED demand, significant access blocks, and subsequent poor patient outcomes.

1.3.2 Time delays due to aviation/ ground transport logistics

Efficient and timely access to healthcare services have been shown to positively improve patient outcomes[35]. However, barriers to timely access will delay patient treatment and interventions. Time delays have been associated with increased patient morbidity and mortality[36,37]. Delays are an inefficient use of resources, yet are an inherent risk of IHTs[36,38]. Time delays specific to air ambulances predominately occur due to weather-based aviation restrictions, aircraft maintenance, and ground transport logistics[39].

Firstly, aviation rules pertaining to weather are set by the Civil Aviation Safety Authority (CASA) in Australia[40]. CASA requires pilots to plan for alternate flight paths when poor weather is forecasted. Alternative plans may change the destination location and estimated time of arrival, and are impacted by airstrip conditions and the amount of fuel required[41].

Secondly, transport delays may occur when aircraft are removed from service during mandatory aircraft maintenance[41]. While maintenance can be scheduled, it ultimately results in reduced numbers of available aircraft and a potential backlog of transfer needs.

Thirdly, delays may occur while aeromedical teams wait for ground ambulance transfer[39]. For example, fixed-wing aircraft may require landing at an airstrip located away from a hospital. In these scenarios, ground transport is required from the airport to the hospital or during medical handover at the airport tarmac. Precise logistics are required for ground ambulances to arrive as the aircraft lands. If an air ambulance waits for ground ambulance transport, the overall efficiency for both is reduced. However, quality improvement processes that include quarterly reporting followed by developing and delivering strategies to improve the process may be a solution, as it has the potential to increase efficiency[43]. Public reporting of service and patient outcomes will be further discussed in section 1.4.

1.3.3 Allocation of limited resources

Aeromedical retrieval is a limited resource. Two Canadian studies, for example outlined how few aircraft are generally available for to service a population. Nova Scotia, with a population of 1 million people, had access to one Sikorsky S-76 and one backup fixed wing aircraft[44]. Ontario had the largest fleet of air ambulances in Canada, with eight fixed-wing Pilatus Next Generation PC-12 airplanes and twelve Leonardo AW-139 helicopters, to serve more than 14 million people in the area[45]. Norway was one of the top four countries in the European Union (32 countries in total), for the number of helicopters per population, per country[46]. However, Norway's population of 5.2 million had access to only twelve HEMS bases and seven fixed wing bases[47]. Air ambulances are an exceptionally limited resource. There is no guarantee of availability and access to care may not be equitable, particularly in rural and remote communities in which aeromedical flights require significant time due to great distances.

Measuring the performance quality of an aeromedical service is challenging due to its inherent allocation limitations. Four performance measures identify how effectively and efficiently resources are allocated and utilised: overtriage, undertriage, secondary overtriage, and potentially avoidable transfer.

Overtriage is defined as "utilisation of a resource to those that may not benefit"[48]; it is the wasteful use of a limited resource[48]. For example, a patient may use aeromedical services while they are stable, without urgent need, with access to ground transport, and within a short distance to definitive care. Unnecessary transfers take vital transport services out of availability for when a true urgent transfer is required[49].

Undertriage is defined as "not utilising a resource to those that could benefit"[48]. For example, an unstable patient with high urgency would benefit from aeromedical retrieval, but no aircraft is available, or a high acuity patient is not identified as very sick and are not aeromedically retrieved to higher levels of care. Failure to identify and execute timely transfers is closely linked with poorer patient outcomes[50].

Secondary overtriage occurs when an aeromedical transfer bypasses capable and available hospitals and is received at a hospital level beyond what is necessary, such as when common emergency general surgery (EGS) procedures like appendectomies bypass regional hospitals and are performed at tertiary hospitals. Secondary overtriage places an unnecessary and expensive burden on the whole emergency medical system[51] by reducing efficiency in tertiary EDs and takes patients away from their community support[6,52]. While previous studies have examined secondary overtriage for trauma[53], few have explored secondary overtriage for EGS in a 'hub and spoke' regional referral structure.

Finally, aeromedical IHTs that result in a discharge from the ED may be considered a potentially avoidable transfer[54], especially in cases where aeromedical patients do not require the receiving facility's resources and are well enough to leave the receiving facility.

While it is known that IHTs are necessary, inefficient use of resources requires further scrutiny[54,55]. Measuring the quality of service provision of a limited resource such as air ambulances should be measured using data that excludes overtriage, undertriage, secondary overtriage, and potentially avoidable transfers, as these are indicators of the level of care at the sending and receiving facilities, admission pathways, and patient disposition. Improved understanding of these patterns may help identify if an air ambulance service is reaching a quality mark.

1.3.4 High patient acuity and multiple co-morbidities

Patient mortality is a frequent measure of quality care provision[56]. However, this patient outcome measure, when applied to air ambulance patients, may be skewed by the high acuity and multiple co-morbidities of air ambulance patients, and not represent retrieval service provision per se[4,56]. Studies have shown that IHT patients tended to be older, sicker, have increased comorbidities, are less racially diverse, and more likely to use alcohol than those not transferred[38]. Measuring the quality of an aeromedical service will be complicated when the nature of the emergency medical system typically transfers high acuity patients with significant co-morbidities. One solution to correct for this is to measure more than just morbidity and mortality by incorporating patient and service data that spans multiple settings, including data from prehospital and hospital-based pre-flight, flight transport, and after-flight hospital inpatient.

1.3.5 Significant heterogeneity among air ambulance systems

Aeromedical services around the world have significant heterogeneity, varying in structure, governance, and management[24], and there is currently a lack of universally accepted standard measurements among air ambulance services[24]. Heterogeneity of data renders it incomparable[19]. For example, an aeromedical service may start measuring treatment time from the time when the aircraft lands at the scene of an accident (i.e., “wheels-down”), while other services may start measuring from when the clinician is physically with the patient. The time difference between these two measurements may range from a few seconds to many minutes. Comparison of discrete event times as a quality indicator will be very difficult in this example. Understanding aeromedical event time is critical to measuring efficiency, effectiveness, equity, timeliness and overall quality of a service[19]. Event time comparison is possible with reporting transparency and full disclosure of precise timestamp structures[19]. At the commencement of this study, there had not been an exploration into the timestamp variations in between aeromedical providers in Central Queensland. The broad event time blocks are: pre-activation interval (yellow block in Figure 1.1), response interval (green block in Figure 1.1), scene interval (blue block in Figure 1.1), and transport interval (red block in Figure 1.1). The top diagonal lines represent general, discrete event time (i.e., timestamps).

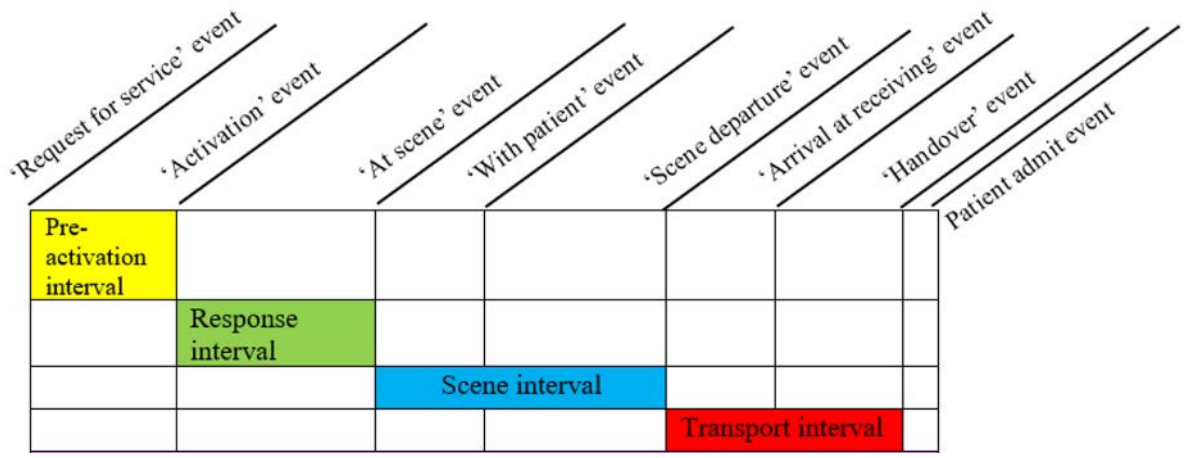

Figure 1.1 Discrete air ambulance event times (top diagonal events) among generally accepted event times (coloured blocks)

1.4 Public reporting of patient and service outcomes

Public reporting can be broadly defined as the provision of meaningful information about an organisation to a large audience[57]. The conventional theory behind public reporting and other activities aimed at increasing quality transparency is that collecting quality outcome measures, such as delays waiting for ground transport, and making them publicly available to patients, their peers, policymakers, and the media, will persuade health care providers to strive for high-quality care provision[57,58]. However, there is currently a gap in assessing the value of aeromedical services. No collection of outcome measures or a quality framework is suitably balanced and transparent, meaning we are currently unable to optimise future improvements of the service.

The Queensland Government committed to public reporting of health service quality and patient outcomes in 2009[59]. Economic theory assumes that public reporting corrects asymmetries in knowledge, by making previously unknown health provision more transparent so everyone can use the information[58], and behaviour-change theories assume that accessible information on processes and outcomes create incentives and goals for improvement[58]. However, there are limited reporting frameworks, especially those specific to air ambulances, which are measurable, meaningful, and manageable for a wide audience[60].

1.5 History and development of the air ambulance service

The term, 'air ambulances' was first used by author Jules Verne, in 1866 *Robur le Conquerant*[61] where a hot air balloon named the Albatross, was used to rescue shipwrecked sailors[61]. In 1870, militaries used hot air balloons during the Siege of Paris[61]. In World War I, airplanes were used to evacuate wounded soldiers from French battlefields[62]. In 1917, the British military used Airco DH9 airplanes (later called Havilland DH9s) to transport their war-wounded in Turkey[62]. While the first 'flying nurses' were established in 1936, called the Aerial Nurse Corps of America[61], the wide adoption of flying nurses' assistance on the frontline fully developed in 1942, during World War II. During this time, 500 flight nurses served as part of 31 medical military transport allied squadrons[61].

Air ambulances called mobile army surgical hospitals (MASHs) were used during the Korean War (1950-1953) as quick and agile medical transports to the nearest field hospitals[63]. General audiences will identify helicopters in the opening scene in the familiar TV series *M*A*S*H*, which depicts nurses and doctors running toward a Bell H-13 to move a war-injured solider. Helicopters provided transportation and medical support to improve the soldiers' chance of survival in the Korean War, as they offered faster retrieval time, more agile navigation, a smoother ride for the patient, and helped to minimize ground traffic[63]. Korean War helicopters performed complex missions with a wider scope than frontline retrievals. They were tasked to transport deceased soldiers, POWs being returned at the end of the war, soldiers with diseases, and injured soldiers from MASH units to formal hospitals, far away from the frontlines[63]. The Korean War air ambulance service was interconnected with other health services in the early 1950's, but it wasn't until 1969 that the first civilian air ambulance programs were established in America[62]. In response to the high rates of vehicle fatalities in the 1960's and the lack of pre-hospital training in advanced life-saving techniques, the National Academy of Science (NAS) (USA)[64] highlighted how Korean war soldiers had better life expectancy than civilians in road side vehicular accidents[64]. In a 1966 white paper by the NAS, specific air ambulance deficiencies were noted: "helicopter ambulances have not been adapted to civilian peacetime needs"[64] (pg. 6). This evaluation paved the way for future advances in air ambulance service delivery.

1.5.1 Australia's historic contribution of the air ambulance service

The Australian history of air ambulances began with Reverend John Flynn[65]. In 1911, his vision of rural and remote Australia was to provide a 'mantle of safety' for people "to build sustainable community despite the hardships of outback life"[65]. The first organised flight, 'an aerial experiment' which would later be known as Royal Flying Doctor Service (RFDS), took off in Cloncurry, Queensland in 1928[41] with the help of Hudson Fysh, the founder of QANTAS airlines, who agreed to use their airplanes as designated air ambulances[41]. The respect for Flynn's work was commemorated in 1994 with his image printed on the Australian twenty-dollar note. After the first flight in 1928, RFDS began to expand across the country[41]. Each state established their own bases and leadership. The Queensland section was registered in 1939 in Cloncurry[41], but the base was relocated north in Mount Isa in 1964[41]. In the late 1960's, RFDS nurses could also be pilots[41]. One well-known RFDS nurse and pilot, Robin Miller Dicks combined her passion for caring for people and her love of flight to help people in need of polio vaccines[41]. Current RFDS development is discussed further in section 1.8.

It was around the late 1960's, that emergency medicine (EM) as a speciality was beginning to take shape[66]. The development of EM specialisation was driven by several factors, including a need for improved transportation such as aeromedical, which increased patient access to emergency care[66], and the rise of hospital-based medicine [66].

The air ambulance service in Australia has progressed to the level of becoming a medical sub-speciality[67]. In 2021, the Australasian College of Emergency Medicine (ACEM) collaborated with the Australian and New Zealand College of Anaesthetists, The College of Intensive Care Medicine, the College of Rural and Remote Medicine and the Royal Australian College of General Practitioners to present a Diploma of Pre-Hospital and Retrieval Medicine (PHRM) for the intended purpose of rapid response medical care provided to seriously sick and injured people[67]. As the PHRM subspecialty continues to develop it will require tools to measure how providers meet target goals and processes toward improvement[67].

1.6 Australian healthcare context

Australians enjoy the rewards of a high-performing health system. Recent health system ranking placed Australia 1st in health care outcomes, but in access to care Australia was ranked 8th against eleven high-income nations such as America, Canada and UK[68]. Not surprisingly, the Australian Department of Health aims for the system to be "more accessible to all Australians, where they live or whoever they are"[69]. Specifically, National health priorities focus on improving timely access to quality care in public hospitals to improve service provision in emergency services, and remove disparities for people living in rural areas[70]. The seven Australian States and Territories are responsible for their own patient transport systems, such as aeromedical retrieval, with varying available funding and management[71].

1.7 Queensland's public health structure: General management and expenses

In Queensland, public health services are delivered in sixteen hospital and health service regions (HHS)[72]. Each HHS is a statutory authority 'set up by law which is authorised to enact legislation on behalf of the relevant state', and governed by a hospital and health board[72]. The Queensland Department of Health (QDH) oversees the management of the public health system and monitors the performance of all HHSs[73]. Service agreements exist between the QDH and each HHS, which determine the provision of health services, teaching, research, and other services[73]. The QDH funds service provision and monitors the arranged outcomes and performance of each HHS[73]. There are four funding models: activity-based funding (utilised in 39 public hospitals), a national efficient cost model (utilised in 76 small rural hospitals), a model for non-admitted mental health, and a model for population-based community services including residential aged care[73]. In 2018-2019, the QDH total reported expenses was $18.1 billion dollars[74]. During this period, health was the largest piece of the state's expenditure (37%), followed by education (19%)[74]. Total expenses for the 2019-2020 QDH budget was $21.735 billion[75]. In response to the COVID pandemic, the 2020-2021 budget may have incurred considerable increases in expenses.

1.7.1 Regionalization: Strategy for equitable access to healthcare

Public health systems aim to provide equitable access to healthcare for all citizens. One strategy to widely deliver healthcare in an integrated structure is a 'hub and spoke' design where the main hospital facilities are located in a 'hub' and deliver a wide range of services and resources. The surrounding, smaller hospitals and clinics work as the 'spokes', offering fewer available services and resources. Other terms for this type of model are emergency care networks, regional care systems, or regionalized health care[76-78]. There are five known advantages to the 'hub and spoke' structure[76-79]:

1. Policy and governance consistency throughout the structure. As the main 'hub' has more resources, they will issue and enforce policies that best fit the system. There is benefit in the uniformity of healthcare delivery;
2. Decreased waste and reduced duplication of services, thereby reducing cost, as higher levels of service and resources are located in the hub;
3. Strengthened quality care delivery, as the 'hub' specialist services are high-volume service centres which improves patient outcomes;
4. Augmented market coverage, as the 'spokes' may allow expansion when and where they are needed, providing a high degree of scalability; and
5. Enhanced agility, as the 'spokes' are more easily able to respond to market changes and community needs.

This structure may serve as a solution to the challenge of equitable access. However, there are seven risks and barriers to an effective 'hub-and-spoke' structure[76-79]:

1. Overcrowding at 'hub' due to the incoming flow from multiple 'spokes';
2. Delayed or prolonged access to care at the 'hub' after a transfer from the 'spoke' due to long distance or inadequate transportation options;
3. Staff frustration at 'spokes' where there is a lack of autonomy;
4. Adverse events in the transport of critically ill patients;
5. Reduced clinical skill and expertise at the 'spokes';
6. Creation of a non-patient centred system that ignores the value of receiving care closer to patient home and community supports; and
7. Poor data linkage across hospital units such as ED, inpatient hospital, and death, which results in poor performance measurement[76-79].

Overall, the 'hub and spoke' structure may serve as a solution to the challenge of equitable access of healthcare[78] but the solution is not without risks. These risks may be minimized with adequate preparation and action by the leaders in the structure[78]. The next step is to explore if these solutions are found in rural and remote communities separated from the 'hub' by significant distances.

1.8 Queensland's aeromedical service

The Queensland Department of Health oversees the Prevention Division and the Aeromedical Retrieval and Disaster Management Branch of the state-wide air ambulance service called Retrieval Services Queensland (RSQ)[80] to ensure "single, state-wide access to a consistent and integrated clinical coordination capability and delivery of stateside retrieval and transport services."[80]. Governance is managed by the State-wide Integrated Governance Group (STIG), which includes nursing and medical directors from all clinical service providers[81]. The function of STIG is to provide transparency of their activities, including clinical incidents, key performance indicators, and clinical quality indicators, to "focus on a partnership for safe and quality patient care, irrespective of organization"[81].

In Queensland, the air ambulance bases maintain a variety of aircraft types (rotor, fixed-wing) and medical staff type (nurse, paramedic, doctor), depending on the needs of the local community[80]. Air ambulance emergency service coordination in Queensland covers 1.850 million km^2, to care for over 5 million people[80]. Ten rotary aircraft bases and 7 fixed-wing aircraft bases task 21 aircraft travelling 5 million kilometres a year covering the entire State, from Torres Strait up in the north down to Coolangatta in the south-eastern corner, to facilitate over 20,000 hospital transfers and rescues in 2019[80]. In Queensland, health regions were established in 2012 to decentralise care and improve management of local health needs[82]. Air ambulance coordination and State EMS communication are centralised via two coordination centres in Brisbane and Townsville[83]. RSQ employ 50 nurses, seven medical officers, 19 support staff and 15 Queensland Ambulance Service emergency medical dispatchers[83]. They operate around the clock all year. The Coordination Centre utilises multi-discipline expertise to inform complex decision-making[83]. Services include: aviation, medicine, nursing, meteorology, ambulance, and search and rescue. These experts determine aeromedical tasking related to weather status, patient acuity and urgency of service need, travel distance, ground transportation logistics, available aircraft, level of required clinical care, and availability of hospital facility, aircraft, and medical team[83].

The Royal Flying Doctor Service (RFDS) and LifeFlight Retrieval Medicine Australia (LRM) are two large service vendors to RSQ[83]. Both organisations manage and maintain patient databases for administrative, clinical, and financial purposes[84]. Data-sharing between RSQ and LRM & RFDS is regulated by contracts[84]; it's likely the RSQ contracts between LRM and RFDS have variations and as such, the data-sharing requirements between these sources will have variations as well[84].

RFDS maintains a modern fleet of airplanes which can typically accommodate one pilot, one or two nurses, doctors (when necessary), and several patients (cabin configuration can change dependent upon need)[41]. In Queensland, RFDS utilise King Air B350 C and B200C[41]. The typical range of these aircraft are 3,000 kilometres and a maximum speed of 305 knots (564 kilometres per hour)[41]. Nationally, RFDS maintains 77 airplanes and the fleet continues to grow[41]. LRM have been serving Queensland for more than forty years with the most recent addition of three Challenger 604 jets to their fleet[85]. LRM maintain 10 community helicopters and 150 critical care doctors, with 9 bases in Queensland and Singapore[85].

1.8.1 Types of aeromedical tasks and clinical skills required

There are generally two main types of aeromedical tasks: interhospital transfers and primary (i.e., roadside) retrievals[86]. Interhospital transfers (IHTs) transport patients from one hospital facility to another, also called interfacility or secondary transfers. In general, the most frequent type of IHTs move patients from a lower level of care to a higher level of care, but aeromedical retrieval may also transport patients from higher levels of care to lower levels. These back-transfers (also called step-down transfers) continue patients' care at hospital facilities appropriate to their needs. Additionally, aeromedical retrieval may be used to transport patients from non-hospital facilities, such as aged-care facilities, to a hospital or the reverse, from hospitals to non-hospital facilities. Clinician skills required for patient management in IHTs range from high to low acuity, unstable to stable, and urgent response to less urgent. Clinician qualifications necessary for IHTs may be a mix of nurse-only, nurse/doctor, nurse/paramedic, or doctor/paramedic.

On the other hand, primary retrievals focus on trauma and urgent patient needs outside of a hospital or health facility, such as work sites or a rural cattle paddock[4]. Clinician skills required in primary tasks must include challenging field situations (i.e., patient entrapment in vehicles), difficult patient assessment (i.e., blunt abdominal trauma), and efficient communication and delegation (i.e., mass causality). Clinician qualifications for primary tasks generally require higher-level nurse or paramedic training to team with emergency or anaesthetist-specialist doctors.

1.8.2 Aircraft types

In general, hospital and health services either own or contract the use of speciality-dedicated helicopters and/or fixed-wing aircraft. Helicopters generally have a smaller fuel capacity and therefore a shorter potential flight distance, with cost and time efficiencies up to 400-500 kilometres[87,88]. However, in general, helicopters have a faster take-off time compared to fixed-wing aircraft[88]. Helicopters can accommodate flexible landing areas (e.g., small open paddock), and can hover without landing to allow clinicians access to environments such as steep slopes[89]. Fixed-wing aircraft, on the other hand, require suitable landing sites (i.e., lighted runways and smooth surfaces), and generally have fast flight times and are more cost-effective for longer distances (>300 kilometres) and time effective for transport over 500 kilometres[87,88]. According to authors Brandstrom et al., rotor-wing systems are more expensive than ground transport or fixed-wing aircraft[87], but the choice of aircraft for a task can depend on visibility, time-to-take-off, flight speed, or aircraft availability[90]. Either aircraft type can provide the advanced modalities typically found in EDs or ICUs, including portable mechanical ventilation, infusion pumps, and cardiac monitoring. Specialised modalities such as ECMO (discussed in section 1.1) are able to be used in either aircraft. During the COVID-19 pandemic, patients requiring ECMO were able to use air ambulance transport under rigid safety guidelines[91].

1.8.3 Clinician skill mix and training

In Australia, training to become a doctor includes an undergraduate degree, a four-year master's degree, one year of internship, and one or two years of provisional training [92]. In general, medical, nursing, and paramedic staff working in aeromedical retrieval may have backgrounds and experiences including emergency medicine, critical care, or anaesthesiology. According to the Australian Health Practitioner Regulation Agency (AHPRA), paramedic education and training in Australia can be a Bachelor of Science degree of three or four years, or a one-year Diploma degree[93]. Professional streams for paramedics include basic, intensive care (ICP) or critical care (CCP), and retrieval (RP) or general care (GCP)[93]. Nurse education and training in Australia has three scopes of practice: enrolled nurse, registered nurse (generally a three year bachelor degree), and nurse practitioner (advanced practice nurse)[94]. National bodies create standards to guide professional practice, such as the Nursing and Midwifery Board of Australia (NMBA)[95] for nurses, the Civil Aviation Safety Authority (CASA)[96] for pilots, and the Australian Medical Council (AMC)[92] for doctors. There are also clinical management standards for medical specialities such as emergency medicine, critical care, or anaesthesia[97,98].

1.9 The Central Queensland region

The Central Queensland Hospital and Health Services (CQHHS) district covers a geographical area of 114,000 kilometre[2,] and had an estimated resident population of 217,449 in 2012[82] with average annual population growth of 2.3%[99]. The 2012 Australian census occurred during the study period, and so the results from the 2012 census are used in this paper. The CQHHS region is classified in the Accessibility/Remoteness Index of Australia (ARIA+) with accessibility ranging from Inner Regional (67.7%), through Outer Regional (23.2%) and Remote Australia (6.8%), to Very Remote (2.2%)[100].

The Queensland State Government owns and operates their largest public hospital system in Rockhampton, with a capacity of 246 beds[82]. Seventeen other small hospitals, rural health clinics, and multi-purpose health services are located within the CQHHS boundary[82]. Local Government Area (LGA) (i.e., municipalities) post codes were used to define the areas of inclusion in this study[101]. The LGA regions of Central Queensland include Banana Shire Council, Central Highlands Regional Council, Gladstone Regional Council, Rockhampton Regional Council, Woorabinda Aboriginal Shire Council, and Livingstone Shire Council[82]. Towns within these LGAs include Baralaba, Biloela, Blackwater, Yeppoon, Emerald, Gladstone, Moura, Mount Morgan, Rockhampton, Springsure, Theodore, and Woorabinda[99]. Two small, private hospitals are located within the Rockhampton city limits[102].

The city of Rockhampton lies on the Tropic of Capricorn, approximately 30 kilometres inland from the Eastern coast of Australia. Rockhampton has approximately 118,000 inhabitants over an 18,000 kilometre^2 land area with a population density of 6.6 people per square kilometre[102]. Services provided by the Rockhampton Hospital include a 24-hour emergency department, a general outpatient department, inpatient wards for general medical, general surgery, critical care, paediatric and maternity, behavioural health, oncology, palliative care, medical and surgical subspecialties, radiology, and rehabilitation. Seventeen other small hospitals, rural health clinics and multi-purpose health services are located within the CQHHS boundary[103]. Public health facilities within CQHHS lack services including interventional radiology (including clot retrieval for ischaemic stoke treatment), interventional cardiology, cardiac angiography, neurology, neurosurgery, dedicated surgical trauma teams/burn unit, neonatal intensive care, paediatric intensive care and transplant units. Medical and surgical subspecialties (e.g., urology, dermatology) in CQHHS are not available on a 24/7 basis [103].

The CQHHS district was chosen as a pilot study site for two reasons. Firstly, it was chosen due to my personal familiarity with the district as an inhabitant and a stakeholder in providing equitable patient care. Secondly, it was chosen for its referral structure; CQHHS lacks a tertiary health facility. CQHHS patients with specialised needs are referred 800+ kilometres southeast to Queensland's capital city, Brisbane, or 750+ kilometres north to Townsville, to receive definitive tertiary care (map is included in chapter 5, supplementary S4 and S5). The significant distances limit ground transport options for Central Queenslanders requiring high-level, urgent, or time-sensitive diagnostics or interventions as they take over an hour to access. The one-hour transport interval is outside European and American aeromedical service comparisons, as highlighted in chapter 2. Therefore, managing patient needs require the logistics of air ambulances.

1.9.1 Central Queensland: A hotspot of health inequality

The town of Mount Morgan, located within Central Queensland Hospital and Health Service, was identified by the Grattan Institute as one of the nation's 10 worst preventable hospitalisation hotspots[104]. These hotspots may point to a health system problem or failure in the community, but there is no 'single solution'[104]. The issues are complex, diverse, and require individual assessment. Ten other towns within CQHHS are listed as 'Priority Places' which identifies enduring disparities. Author S. Duckett recommends developing tools to precisely identify preventable hospitalisation hotspots to efficiently reduce health inequalities and build an evidence base to address health inequalities more broadly[104]. Therefore, one hotspot town in CQHHS, and ten CQHHS towns which are “priority places”[104] further demonstrates CQHHS as an appropriate pilot study.

1.9.2 Air ambulance service relevance to rural communities

Aeromedical retrieval provides rural and remote communities access to the emergency medical system. However, according to Australian Institute of Health and Welfare (AIHW), people in remote, rural, and regional communities are currently at an increased risk of mortality due to total disease burden, trauma and injury (e.g., agricultural, motor vehicle, mining-related, self-harm and domestic violence), and potentially preventable hospitalisations compared to people in urban areas[105]. Additionally, rural and remote communities experience a decreased life expectancy, increased chronic disease, decreased access to GPs and specialists, and poorer health literacy than their urban counterparts[105-107]. In these communities, men have poorer health outcomes than women in general[108]. To compound the problem, the current Australian Government has identified significant doctor shortages in rural communities with higher burdens of disease[109]. To combat the shortage, the Australian government committed $550 million dollars in the 2018-2019 budget to strengthen the recruitment and retention of doctors in these communities[110]. Also unique to very remote and rural communities in Queensland is the rotation of junior medical doctors, who often have limited resources and support[111].

Closing the disadvantage gap of rural communities is a key performance objective for the National healthcare system[112]. However, the outcomes for patients in rural, regional, and remote Queensland requiring interhospital aeromedical transfers is largely unknown. Better understanding of aeromedical retrieval to and from rural and remote communities is a step toward the national goal of equitable & accessible healthcare[108]. Further exploration of the perceived supports and barriers rural clinicians face in the process of referring patients to higher level of care by air ambulance may minimise errors like over- and under-triaging, discussed in section 1.3.3.

Rural communities in Australia are separated from urban tertiary health centres by significant distances, but the use of medical helicopters and air ambulances make distance a surmountable challenge. Rather than distance, it is *time* that now confronts emergency service equity for rural and remote areas of the country. A common phrase in emergency medicine is ‘time is tissue’, because in events where blood flow or oxygen supply ceases, tissue quickly dies. ‘The golden hour of trauma’ is a medical phrase relating to time, not distance. Long time intervals, rather than distance from tertiary centres, has been correlated with higher mortality for stroke and acute coronary syndromes[114,115]. Time needs to be the focus, but the time it takes rural and remote patients in CQHHS to reach definitive care, and the processes affecting these time periods, is poorly understood.

1.10 Understanding the rural, remote and regional aeromedical patients’ journeys

Currently, CQHHS is well-positioned to evaluate patient and service outcomes by constructing patient episodes: where they come from, where they are going, how long the journey took, their illnesses, and their disposition. The author’s working definition of these episodes, called the ‘aeromedical patients’ journeys’, is an integrated continuum of care that spans multiple settings, including the prehospital and hospital-based pre-flight period, the flight transport period, the after-flight hospital inpatient period, and the patient’s overall disposition (discussed in further detail in chapters 5 and 6). Better understanding of the aeromedical patients’ journeys will help to develop appropriate delivery of regional health services.

To create aeromedical patients’ journeys, de-identified health data was collated and linked from multiple sources across the spectrum of care. This resulted in a comprehensive picture of the patients' clinical journeys and of the services utilised in the regional health care system. Linking patient and service data furthers the capacity for understanding of the patient experience[116]. Additionally, as discussed in section 1.3.1, it is important to understand who uses the ED, how they use it, and what do patients need at the ED, in order for demand management strategies to achieve their objectives[117]. Linking patient and service data can help to answer these questions. This study provides a step toward understanding those fundamental questions.

Queensland Health (QH) has a wealth of big data at its disposal[118]. However, the information from patient records is maintained within independent departments. Linking health data bases together aligns with QH eHealth strategy, which calls it "the key to the provision of high quality, valued healthcare services, improved patient outcomes and reduced patient risk"[119] (p. 42). Linking emergency service databases will allow for more connections between clinician providers, and assist in accurate planning & service delivery[120,121].

Linking health data anticedent and subsequent to aeromedical retrieval provided insights into health patterns within the health system. According to AIHW, "by bringing together data, we can gain important insights into people's pathways through the health system and experiences of their own health, such as the relationships between different chronic conditions and the services and treatments, yielding the greatest improvements in health outcomes and the quality of life."[112]

Health data linkages in Queensland has been one of the "high-priority areas for research and policy related to data science in the ED", as identified by a joint committee consisting of members of both the Society for Academic Emergency Medicine and the American College of Emergency Physicians Research Committees[43]. Linking databases will enable epidemiological monitoring, surveillance, analytical assessment, and prospective modelling of aeromedical populations (e.g., length of stay, death rates, ICD code)[122]. Examples of models and surveillances include:

- Initiating follow-up studies (e.g., hospital readmission rates, mortality following ED discharge)
- Investigating risk factors for future mortality & morbidity studies, such as trends for particular pathology outcomes (e.g., blunt abdominal trauma, coronary artery disease, suicide, elderly falls, etc.)
- Validating and improving quality data
- Support disaster- and emergency-response strategies[123].

Data linkage has also informed health economics. Western Australia, for example, has been linking health and welfare data for 18 years, which has been used to change a range of policies including Duty to Care[122]. In Queensland, select groups of patients were linked with their related inpatient International Classification of Diseases (ICD) codes to explore hospital utilisation cost outcomes[124].

Currently, there is a paucity of information to describe who is retrieved, what happens to these patients, how often they fly, or how many flights are required before they reach definitive care. Care coordination data is severely fragmented[125], and at the commencement of this study, clinicians were not able to readily and easily obtain electronic data for aeromedical patient outcomes. Clinicians were able to perform individual chart reviews, but this is a time-intensive process. Linking patient data from multiple sources provides "safer, timelier, efficient, effective, equitable, patient-centred care."[125] (pg. 216). The findings in this study will provide innovative, high-quality feedback regarding patient and service outcomes.

1.11 Alignment with key strategies of emergency service provision

Linked data that will increase understanding of aeromedical retrieval and transfer to/from rural and remote communities is a step toward the national goal of equitable and accessible healthcare from the National Health and Hospitals Reform Agreement 2020-2025[70]. The study aligns with the 2026 Queensland eHealth goals, 'Connecting Healthcare'[118], specifically, goal six – "better coordinated care through increased collaboration, digitally enabled care pathways across care settings and the secure sharing of information" – and goal seven – "improved access to expert knowledge more easily, anywhere and in real-time, enabled by technology". The study also aligns with the *Care4Qld* strategies for an improved ambulance transfer process in crowded EDs and better coordination in improving access to emergency care in Queensland[126].

1.12 Gaps in current knowledge and rationale for this research

This first-of-its-kind study in aeromedical retrieval seeks to link together the existing but separate databases in Emergency Department Information Systems (EDIS), Queensland Hospital Admitted Patient Data (QHAPDC), Death Registry, and Retrieval Service Queensland (RSQ) to increase the impacts of patient-centred outcomes research, resource allocation, and service planning in the Central Queensland advanced emergency care system. Queensland Health Statistical Service Branch (QHSSB) manage an ongoing Master Linkage File (MLF) between Queensland public hospital Emergency Department Information Systems (EDIS), the Queensland Hospital Admitted Patient Data Collection (QHAPDC), predetermined data from private hospitals, QHAPDC morbidity, and the Queensland death registry[127]. The MLF was used to access data from these sources[126]. At this study's commencement, the RSQ, LRM, RFDS, and Queensland Health MLF were independent and unlinked to each other[128]. Linked data can create a more comprehensive picture of the aeromedical patient journey and of service in the Central Queensland regional health care system, furthering the capacity for understanding and improving the patient experience.

Currently, there is a lack of understanding of the decision-making process of doctors and nurses from rural and remote hospitals and clinics as they care for patients requiring aeromedical retrieval for a higher level of medical intervention. Utilising a qualitative method, such as clinician interviews, will increase understanding of their experiences and perceptions. To date, there has not been qualitative analysis into rural clinician perceptions of requesting aeromedical services in Central Queensland.

1.13 Contribution to knowledge

Knowledge of aeromedical retrieval patterns and emerging trends helps improve patient care, and this study will inform development and quality improvement of the aeromedical retrieval system in Queensland. It also proposes more equitable distribution of resources and equitable access to healthcare in the CQHHS region. A full and detailed understanding of retrieval patterns assists development of education and staffing models in the emergency department and retrieval service.

1.14 Research questions, aim and objectives

Research questions:

1. Can an investigation of current literature create a framework to report on aeromedical services and a regional referral systems' provision of quality care, and inform areas for improvement?
2. Is there value in linked data to better understanding aeromedical patient and service outcomes, including patient origins, destinations, referral pathways, illnesses, deaths, and service time intervals during the study period in regional Central Queensland?

3. What are rural clinicians' self-reported perceptions of requesting aeromedical retrieval in Central Queensland hospitals as they care for suspected appendicitis patients?

Aims:

1. To document the range and nature of aeromedical outcome measures in the literature.
2. To use the results of aim 1 to develop an aeromedical quality framework and use it for reporting existing aeromedical patient and service outcomes.
3. To explore the aeromedical patients' journeys in Central Queensland using linked data.
4. To describe rural clinicians' perceptions of the supports and barriers they experience as they request aeromedical retrieval for patients with suspected appendicitis in Central Queensland.

Overall objective:

To explore the performance of a regional aeromedical system to inform the development of a performance evaluate framework for aeromedical services.

1.15 Thesis structure and organisation

The thesis is by publication, written in manuscript format commonly acceptable for health system analysis. The thesis is built from four studies:

Study 1 is a literature and context analysis which explored the current knowledge of the provision of aeromedical services, their efficiency, and their effectiveness. A scoping review method was selected as it documents the range and nature of aeromedical outcome measures. Content analysis methods were selected to identify key themes. This links to aim 1 and publications 1 and 2.

Study 2 involved the aeromedical-only analysis (Phase 1) and the creation of a linked data set (Phase 2) which details five years' experience of aeromedical retrievals in Central Queensland. The data linked aeromedical, emergency department, hospital, and death data. Phase 1 and phase 2 used descriptive statistic methods. This linked to aims 2 and 3, publication 3 and 4.

Study 3 involved analysis of the linked data specific to acute appendicitis:

1. Described the patient population, their age, gender, locality characteristics
2. Described the referral patterns of transfers and retrievals
3. Described the diagnosis codes
4. Identified the outcomes and compared those outcomes with national or international benchmarks specifically for acute appendicitis.

Study 3 used descriptive statistics and quantile regression was used to determine appendectomy outcome differences. This linked to aim 3 and publication 5.

Study 4 aimed to identify the factors that appeared to impact on decision-making in regard to means of transport and/or retrieval and destination. These involved semi-structured interviews with nurses and doctors to identify the factors that influenced decision-making. Content analysis was used to identify themes. This linked to aim 4 and publication 6.

1.16 Conceptual model of the thesis and organisation

A conceptual model summarises the main aims and outputs from the thesis in flowchart form and is located at the start of each chapter (Figure A). A red box indicates the chapter and its relative position within the thesis. It also indicates the related manuscript title and the publication number. Study 1 is displayed in a rose-coloured box, study 2 in a blue box, study 3 in a green box, and study 4 is in a yellow box.

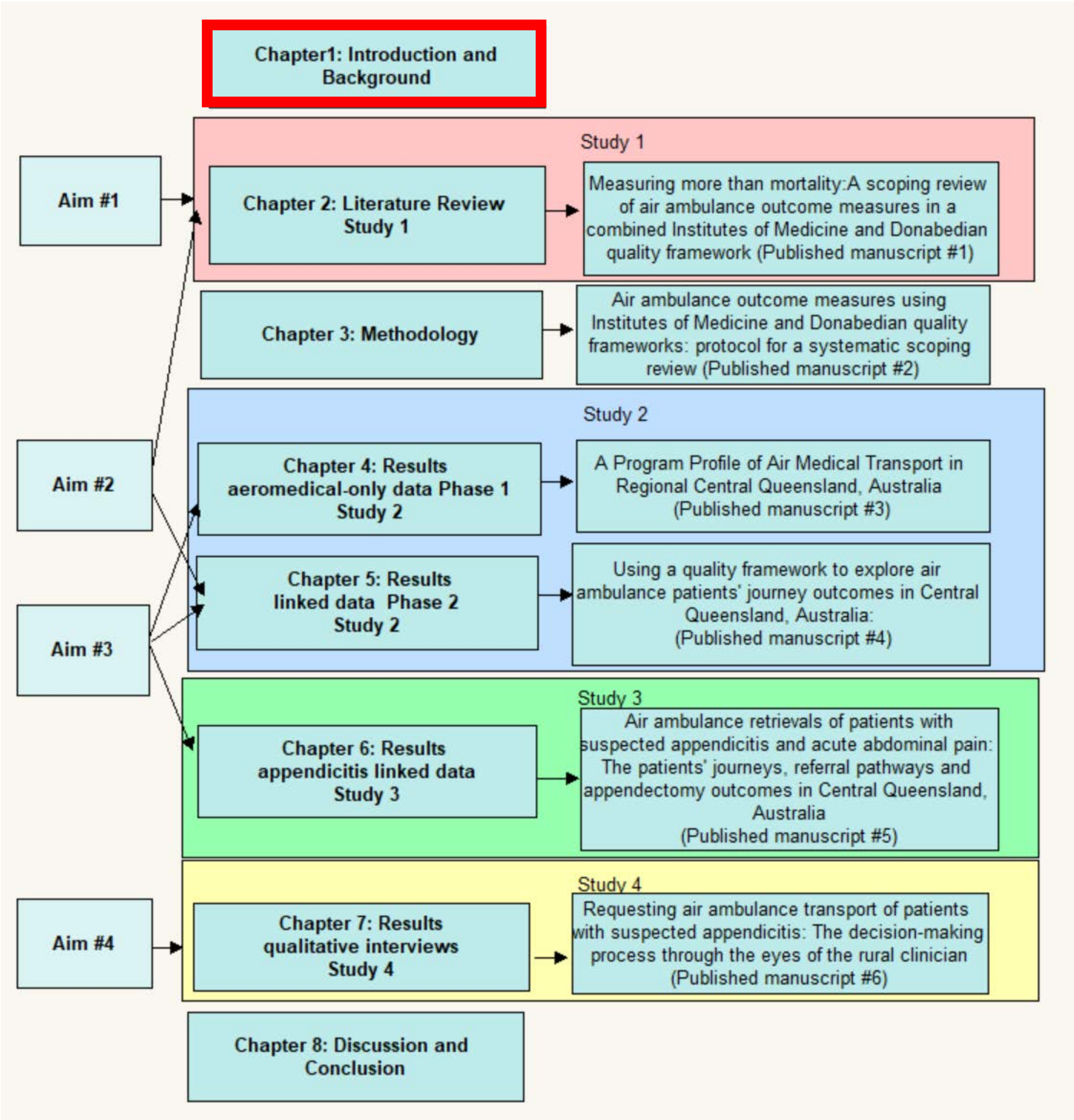

Figure A. Conceptual model of the thesis aims and outputs

Study aims 1-4 are in the boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a rose box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

1.17 Salient points

- Measuring the quality of air ambulance service provision is challenged by five elements. Two relate to interconnected events antecedent and subsequent to aeromedical flight (access block, time delays due to transport logistics) and three relate to the general nature of the emergency medical system (limited resources, high patient acuity, system heterogeneity).

- Reporting health service and patient outcomes encourage behaviour change and facilitate improvement planning.
- Queensland's public health is decentralised in sixteen regional boundaries meant to provide equitable access to care and avoid duplication of services.
- Most hospital and health regions in Queensland have a 'hub and spoke' design, which refers rural and remote patients in the 'spokes' toward higher resources at the 'hub', when necessary.
- Central Queensland Hospital and Health Service covers a large geographic area and includes rural and regional health services, but lacks tertiary services.
- Rural clinicians make patient management decisions with few diagnostic tools, yet little is known of their perceived supports and barriers in the process to refer toward higher levels of care.
- At the commencement of the study, aeromedical patient and service data is siloed. Linked data to events before flight, after flight, and service and patient outcomes such as mortality, flight time intervals, and length of hospital stay, are largely unknown.

1.18 Chapter synthesis

This chapter introduced the main research topics that weave throughout the thesis: measuring a quality health service, current challenges in measuring quality of an aeromedical service, and reporting service and patient outcomes for future improvement planning. Regionalisation (the 'hub and spoke' structure) of health services in Queensland was designed to reduce inequity of access. In Central Queensland Hospital and Health Service, equitable access to care impacts rural, remote, and regional communities due to significant distances and a lack of tertiary services. Finally, this chapter explored the value of linking patient and service data before and after flight that provides insight in the continuum of quality care and its outcomes.

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Chapter 2. Literature review of aeromedical patient and service outcome measures

Overview of this chapter

At the time of this scoping review there had not been a publication which explored the range and nature of aeromedical patient and service outcome measures. According to the Institutes of Medicine, failure to identify the range, variation or gaps in outcome measures hinders the ability to recognize service disparities. Chapter 2 synthesizes the evidence in four phases: 1.) table summary of selected article outcome measures, 2.) content analysis themes, code of outcome measures and independent variables, 3.) narrative description of main themes, 4.) visual dashboard diagram of service priorities and quality strategies. This chapter addresses aim 1 and aim 2.

- aim 1: To document the range and nature of aeromedical outcome measures in the literature,
- aim 2: To use the results of aim 1 to develop an aeromedical quality framework and use it for reporting existing aeromedical patient and service outcomes.

Figure A. summarises the main aims and outputs from the thesis and indicates the position of this chapter within the thesis.

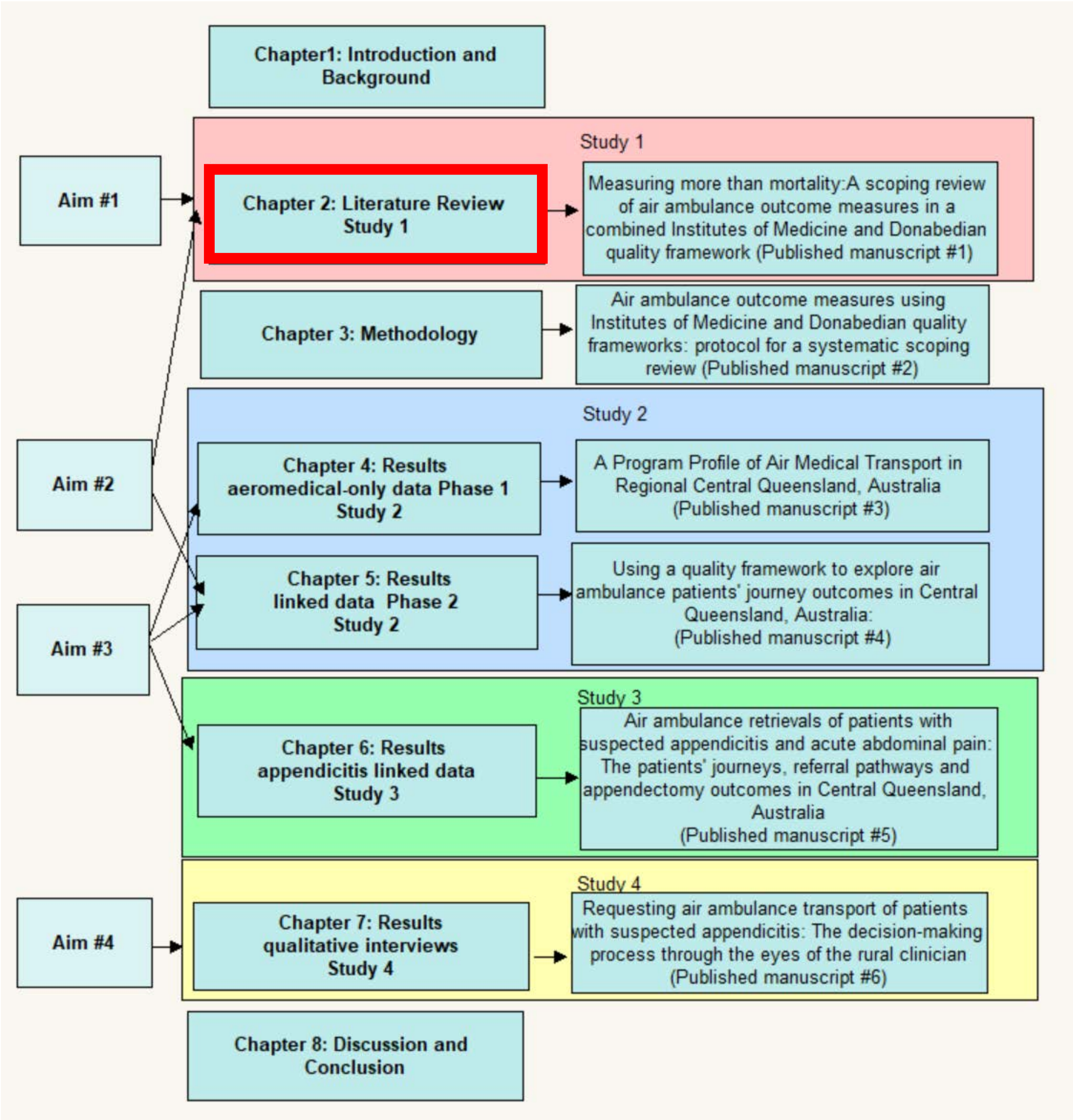

Figure A. Conceptual model of the thesis aims and outputs

Study aims 1-4 are in boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a red box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

This chapter contains the following manuscript that has been published in a peer-reviewed journal, relevant to aeromedical retrieval, and is inserted as a published .pdf in the format required by Australasian Emergency Care:

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Systematic Review

Measuring More than Mortality: A scoping review of air ambulance outcome measures in a combined Institutes of Medicine and Donabedian quality framework

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ABSTRACT

Introduction: Measuring the performance of air ambulance services are complex and dynamic due to the variability and interconnectedness of emergency systems. The aim of this study is to review the range and nature of air ambulance outcome measures published in peer review articles and construct a quality framework based on the results. A scoping review of the literature was conducted to identify outcome measures that evaluate the quality of air ambulance services. Combined frameworks from the Institutes of Medicine (IOM) and Dr. Avedia Donabedian were used to create a dashboard structure for a framework of air ambulance outcome measures.

Methods: A literature search strategy was undertaken, following PRISMA-ScR guidelines and included eight databases over the period 2001-2019. Qualitative content analysis was conducted in 4-phases: 1) table summary of selected article outcome measures, 2) content analysis themes, codes of outcome measures and independent variables 3) narrative description of main themes 4) visual dashboard diagram of service priorities and quality strategies, based on the findings.

Results: Thirty-four articles were screened by full text and eighteen met the selection criteria. Twenty codes emerged and were grouped to form eight consistent outcome themes; asset/ team type, access to definitive interventions, prehospital factors, mortality, morbidity, responsiveness of service, accessibility of service and patient disposition.

Conclusions: A quality framework consisting of eight outcome measures was created, it also identified seven gaps which ordinarily require performance evaluation; patient comfort and satisfaction reporting, cultural awareness training, safety alarms in place to identify volume stress, optimal coordination of resources, cost of service analysis, comprehensive patient journey time and an adaptive referral system analysis. The measures in the framework provide a broad perspective of air ambulance performance we believe will help decision-making and planning to improve patients experience and outcomes.

Introduction

Air ambulances provide rapid response medical care and transportation to seriously sick and injured people [1]. Helicopter or fixed-wing aircraft and crew help to improve patient outcomes by decreasing the time interval from onset of symptoms to definitive intervention [2]. Yet, there is a gap in how to assess the value of these services and thus optimize future improvements.

The Institutes of Medicine (IOM) [3] and Donabedian [4] frameworks were chosen to help structure the work because they are credible, widely accepted and referenced in quality care delivery. IOM attributes identify the depth of quality and Donabedian arranges these in meaningful order, representative of the selected study outcomes.

The unique air ambulance environment presents three significant challenges in developing a framework to measure performance. Firstly, it is rooted in the complexity and interconnectedness of emergency systems [5]. Secondly, there is high variation between system structures, governance and management [6]. Thirdly, aeromedical patient mortality and hospital length of stay may correlate the nature of high acuity and multiple co-

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morbidities of air ambulance patients. Yet, these results may not reflect the service quality [7]. For these reasons, a performance evaluation framework will require a flexible format to accommodate this complex and heterogeneous environment.

The framework will need to be relevant and include near-future realities; pandemics, climate change and global conflict that alter healthcare delivery status quo. Currently, there are three considerable pressures on the sustainability of air ambulance service quality. Firstly, increasing regionalization of highly specialised healthcare systems require patient transportation to higher levels of care [6,8]. Secondly, recent improvements in clinical guidelines have implications that alter air ambulance referral patterns, critical time/ tissue management and resource allocation [9–11]. Finally, increasing utilization of air ambulance service shows no sign of slowing [10,12–15].

Development of an air ambulance quality framework should facilitate critical, thoughtful conversations regarding service and emergency system performance and sustainability. The reporting format should be flexible for the needs of patients, providers and planners [16] and assist to model main objectives of reporting and improvement planning, to improve patient outcomes.

The development of the combined Institutes of Medicine (IOM) [3] and Dr. Avadis Donabedian [4] framework is reported in the scoping review protocol [17]. In summary, the six IOM domains were designed to encompass core needs of quality care:

- *Effective:* providing evidence based care to all who could benefit and refraining from providing services to those not likely to benefit [3],
- *Efficient:* avoiding waste, including equipment, supplies, ideas or energy [3], (authors have included waste of time)
- *Safe:* avoiding injury [3] (authors have included further loss of tissue or deterioration),
- *Patient-centered:* respectful and responsive to patient preferences, needs and values [3],
- *Timely:* reducing waiting and delays for those that give and receive care [3],
- *Equitable:* care which does not vary according to gender, ethnicity, geographic location or socioeconomic status [3] (authors have included age)

The three Donabedian areas were designated domains of focus:

- *Structural Measures:* material resources; facilities, equipment, human resources, and organizational structures [4]
- *Process Measures:* how health care is given and received as guided by policy, standards and procedures [4]
- *Outcome Measures:* the effect of care and its impact on the health status of patients and populations [4]. For the purpose of the review, further definition of outcome measure is used to avoid confusing patient effect from hospital policy (e.g., readmission rates): *Patient outcome measure*: "a health state of a patient resulting from health care" (e.g. physiologic measures, radiology and lab results and morbidity) [18].

The aim of this study was to create a framework of outcome measures to assess quality performance of air ambulance services to help guide future, strategic improvements for patient outcomes.

Methods

The scoping review has been reported in accordance with the Preferred Reported Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [19] and has been registered within the International Prospective Register of Systematic Reviews (PROSPERO) ID# CRD42019144652 [20]. The research questions were: what range and scope of outcome measures are used in air ambulance literature; what tools were used to identify quality of care; which performance outcomes are utilized in our quality framework; and can our framework create a dashboard for strategic improvement? The eligibility criteria included English studies, from January 2001 through search commencement on 01 October 2019, of peer-reviewed observational, cross-sectional, longitudinal, interrupted time series or systematic reviewed studies of dedicated civilian air ambulance missions, on either fixed-wing or rotor. Exclusion criteria include: individual case studies, small case controlled studies outside of the general representative population, equipment or device trials, drug or laboratory trials as these are not relevant to the review aim. Description of the search strategy database outcome, two Medical Subject Headings (MeSH) terms; 1. Air ambulance ("Fixed-wing aircraft or helicopters equipped for air transport of patients") and 2. Outcome and Process Assessment (Health Care) ("Evaluation procedures that focus on both the outcome or status of the patient at the end of an episode of care – presence of symptoms, level of activity and mortality; and the process – what is done for the patient diagnostically and therapeutically"), and hierarchy trees are located in Appendix A, B, C. Our scoping review protocol [17], provides further detail of the IOM and Donabedian structure, intended purpose, review questions, key words, eligibility criteria, search strategy, dates and terms. No significant deviations from the protocol [17] were required. Risk of bias was assessed using ROBIS (Risk of Bias In Systematic reviews) [21] for all selected studies [22–39] and chosen for rigour in assessing the metabias in the systematic review process (Appendix D).

Four-phased synthesis process for content analysis and distribution

A four-phased qualitative content analysis process was undertaken to better understand and identify the common themes in air ambulance outcome measures. The content analysis process was chosen to increase transparency and reproducibility [40]. Categorizing of data was achieved using a origination approach [40] based on the authors combined professional air ambulance and emgerency medical system experience and nature of topics found in current air ambulance and emergency medical system literature. Iterative cognitive reconstruction methods guided each phase by first collecting the outcome measures and independent variables, then working backward to choose codes that identify meaning in the clinical, air ambulance context [40]. Three authors (KHE, MTE, GF) independently identifed codes and themes. Full group concensus was reached, after rigorous discussion, on final codes and themes. Phase 1: summarized selected study variables in table format (Table 1). Phase 2: each of the study's outcome measures and independent variables were identified and coded into unique groups. These code groups formed into larger theme clusters (Appendix E). Phase 3: a narrative format highlighted theme effect differences and similarities. Phase 4: Creation of a visual, strategic quality dashboard, based on consistent performance themes (Table 2).

For the purpose of the review, three key concepts: 'access to care', 'resource utilization' and 'resource allocation' were broadly defined [41] and interpreted in the context of air ambulance health service.

There is a nineteen-year span of time between the first selected study and the last. These dates were intentionally chosen to coincide with improved safety policies from the International Civil Aviation Organization (ICAO) [42], in the wake of considerable air ambulance disasters.

Table 1
Selected studies summary: Interventions/ Comparison/ Primary Outcome/ Measurement tools in chronologic, descending order.

Author	Intervention	Comparison	Primary/Secondary Outcome Measure (POM)/ (SOM)	Independent variables
Ueno et al. 2019 [22]	IHT for acute cerebral infarct	PHEMS vs. GEMS for acute cerebral infarct	POM: Mortality SOM: Functional prognosis for acute cerebral infarct	Age, sex, comorbidity, thrombectomy, distance, rt-PA use, final mRS, time from on set to reaching hospital, call to reaching hospital, HEMS, GEMS
Vaughan Sarrazin et al. 2019 [23]	IHT for mechanical thrombectomy (MT)	HEMS relative to GEMS for Hispanic, non-Hispanic Black relative to non-Hispanic White with stroke	POM: Odds risk of HEMS utilization for MT	Age, sex, distance from MT hospital, GEMS, BLS /ALS /HEMS transport, ICD9-CM, CHA_2DS_2-VASc, cerebrovascular events, Exlihauser, zip code 'demographics', co-morbidity,
Funder et al. 2017 [24]	IHT or outside-of-hospital via GEMS or HEMS for suspected stroke	HEMS vs. GEMS for suspected stroke	POM: Mortality after admission, 30 day SOM: Transport mode on stroke mortality, disability and labour market affiliation	mRS at 3 months NIHSS, system onset, prehospital, in-hospital, procedure time intervals, employment first 2 years, HEMS, GEMS
Schneider et al. 2017 [25]	IHT for STEMI patients to PCI centre	Control vs. dispatch, and hot-load encouraged.	POM: Door -in to door-out time to PCI time interval	Interval time: arrival at referring facility to departure from referring facility
Nolan et al. 2017 [26]	Helicopter transport for trauma patients	Helicopter for trauma patients from scene vs. modified scene vs. IHT	POM: mortality, Trauma severity, SOM: morbidity	Age, sex, MOI, admission VS, GCS, ISS, intubation status, vent days ICU admit, mortality, hospital. ICU LOS, mission type
Brown et al. 2016 [27]	Helicopter transport for trauma patients	Helicopter transport vs. ground transport	POM: Patient in-hospital survival to discharge	Age, sex, MOI, prehospital time, SBP, HR, RR, GCS, ISS, Mortality Prediction Model hospital designation, HEMS, GEMS, ICD9, ICU admission, mechanical ventilation, ED dispo, hospital dispo
Garner et al. 2015 [28]	PHEMS, direct transport for paediatric immersion injury patients	PHEMS direct, scene transport vs. non-physician staffed	POM: Patient mortality, SOM: disability (2 day, 9 day, 30 day)	Age, site, presence or absence of cardiac output, GCS, interventions (crystalloid bolus, intubation, IO, bystander CPR, anaesthesia induction); imaging, PCPC
Hirshon et al. 2015 [29]	HEMS for blunt trauma patients from the scene or from non-trauma hospitals	Mortality and severity; helicopter use	POM: Blunt trauma patient mortality SOM: helicopter use over time.	ISS, predicted mortality according to TRISS, MOI, discharge in 24 hours, hospital admission, 30-minute drive time to TC.
Hannay et al. 2014 [30]	Transport to an urban trauma center for injured patients	Helicopter vs. non-helicopter transport types	POM: Mortality SOM: Patient dispo, interventions, severity	ISS, AIS, GCS, interventions: airway control, PRBC; patient dispo, transport type, MOI
Wormer et al. 2014 [31]	Aeromedical helicopter, primary transport of patients for traumatic injuries	TAC counties vs. non-TAC counties.	POM: Overtriage of aeromedical helicopter, primary transport of traumatic related patients	Discharge within 24 hours, transport arrival, distance, time of flight, MOI, GCS, indication for helicopter requests, ISS, ICU, hospital LOS.
Walcott et al. 2011 [32]	Helicopter, one-way interfacility transfer to the ED for neurosurgical patient evaluation	Helicopter vs. estimated ground transport time interval from ED arrival to neurosurgical start time	POM: Time from helicopter transport of ED arrival to invasive neurosurgical start time	Time from ED arrival to invasive neurosurgical start, demographics, referring hospital location, neurosurgical diagnosis, dispo, hospital LOS, HEMS, GEMS
Reiner-Deitemyer et al. 2011 [33]	1. HEMS(direct) 2. HEMS from another hospital (indirect) 3. Ambulance doc direct 4. Ambulance doc indirect 5. Ambulance without doc direct 6. Ambulance without doc indirect	6 groups: HEMS direct vs. indirect vs. ambulance with ED doctor direct vs. indirect vs. ambulance without ED doctor direct vs. and indirect	POM: Thrombolysis rates SOM: HEMS hospital arrival times	Age, sex, NIHSS, Barthel Index, mRS, prehospital and intrahospital times, risk factors, rates of thrombolysis, previous stroke, hypertension, hypercholesterolemia, atrial fibrillation, cardiac diseases, myocardial infarction, peripheral arterial disease, diabetes, smoking, alcohol abuse.
Brown et al. 2010 [34]	Primary trauma transport to Level 1 TC	Helicopter transport primary vs. ground transport primary in survival or discharge to home	POM: Mortality SOM: Discharge disposition	Age, sex, ISS, MOI, prehospital time (response, scene and total time), GCS, SPB, RR, ICU admit & LOS, vent days, emergent operation, ED, hospital dispo, TC designation, insurance status, survival 24 hours, HEMS, GEMS

Table 1 (*Continued*)

Author	Intervention	Comparison	Primary/Secondary Outcome Measure (POM)/ (SOM)	Independent variables
McCowan et al. 2008 [35]	HEMS for scene trauma direct to Level 1 for pediatric blunt trauma	Rural vs. urban scene HEMS for pediatric (<17) blunt trauma	POM: Mortality SOM: Morbidity for pediatric blunt trauma transported from the accident scenes by HEMS crew	Age, sex, hospital, ICU LOS, dispo, MOI, flight mileage, hospital VS, trauma score, GCS, ISS, ED death, TC designation (adult or peds), procedures (intubation, chest tube, CPR, IV or CVC placement, fluids, blood products)
Konstantopoulos et al. 2007 [36]	HEMS IHT for patients with ischemic cerebrovascular accident	Study period 2000-2002 vs. 2002-2004; Time between symptom onset and stroke center arrival	POM: Activation interval; symptom onset to stroke center arrival	Age, sex, air mileage, symptom onset time in flight, by flight team and receiving neurologist, NIHSS, HEMS activation time.
Davis et al. 2005 [37]	Transport for moderate to severe traumatic head injury, whom benefit from intubation	HEMS vs. GEMS for moderate to severe traumatic head injury	POM: Mortality for moderate to severe traumatic head injury	Age as a surrogate for comorbid disease, sex, MOI, GCS, hypotension, AIS, overall severity in ISS, d/c (home, jail, psychiatric facility, rehab or AMA), HEMS, GEMS
Akmal et al. 2003 [38]	HEMS transportation for trauma patients with suspected spinal injury	Trauma patient ISS vs. FIM scores at 1 year: injury location, type and initial neurology.	POM: Mortality SOM: MOI, FIM	Age, sex, MOI, AIS, injuries, Frankel classification, mortality, spinal injury distribution, pattern, FIM at initial spinal injury, hospital discharge, 3, 6 & 12 months
Oppe et al. 2001 [39]	Helicopter Trauma Team effectiveness	Daytime HTT vs. remaining non-HTT	POM: Mortality SOM: Quality of Life	Time/place/type/severity of injury, patient age, sex, EQ-5D

Key: AIS-Abbreviated Injury Score; ALS-advanced life support; AMA-Against Medical Advice; BLS-basic life support; CHA_2DS_2-VASc-clinical predictive stroke risk score; CVC-Central Venous Catheter; d/c-discharge; dispo-disposition ED-emergency department; EQ-5D-instrument for measuring health status; FIM-Functional Independence Measure; GCS-Glasgow Coma Scale; GEMS-ground emergency medical service; HH-heart rate; HEMS-helicopter emergency medical service; HTT-Helicopter Trauma Team; ICU-intensive care unit; IFT-inter facility transfer; IHT-inter hospital transfer; IO-intraosseous; ISS-injury severity scale; LOS-length of stay; MOI-mechanism of injury; MVA-motor vehicle accident; mRS-modified Rankin Score; NIHSS-National Institutes of Health Stroke Scale; OT-over triage; PCPC-Paediatric Cerebral Performance Category; PHT-physician-staffed helicopter transport; PHEMS-physician helicopter emergency medical; PRBC-packed red blood cells; QoL-quality of life; RR-respiratory rate; RTAC-regional trauma advisory committee; rt-PA-recombinant tissue-type plasminogen activator; SPB-systolic blood pressure; TAC-Trauma Advisory Committee; vent-ventilator; VS-vital sign.
Key: †HCAHPS-Hospital Consumer Assessment of Healthcare Providers and Systems.

Table 2
Strategic Quality Framework: Content analysis themes and codes (Themes are in **bold**, codes are *(italicised in brackets)* and author identified gaps in literature are coded in *grey and underlined).

IOM Domains	Donabedian Structure	Donabedian Process	Donabedian Patient Outcome
	Performance Themes *(codes)* examples		
Effective *providing evidence based care for those that can benefit, refraining from services to those not likely to benefit[3]*	**Asset/ Team Type** *(provider/ skill mix)*	**Access to Definitive Interventions** *(patient treatment/ management)* Example: appropriate to need and clinical standards **Prehospital Factors** *(pre-hospital interventions)*	**Mortality & Morbidity**
Efficient *avoiding waste; equipment, energy, supplies[3], time*	**Asset/ Team Type** *(retrieval type)* Example: Task coordination and dispatch protocols	**Responsiveness of Service** *(compliance of clinical standards)* Example: activation time *Optimal coordination of resources Example: asset 'down-time' *Total cost efficiency of the system	*Effects of direct cost to patient Example: medical bankruptcy rates
Safety *Avoiding injury[3], further loss of tissue or deterioration*	*System safety indicators in place for upward utility trends Example: governance of pre-threshold alarms	**Responsiveness of Service** *(compliance to established clinical standards)*	**Morbidity & Mortality**
Patient-Centred *respectful and responsive to patient preferences, needs and values[3]*	**Accessibility of Service** *(aircraft/ team allocation)*	**Access to Definitive Interventions**	*Patient comfort and satisfaction Example: HCAHPS
Timeliness *reducing waiting and delays for those that give and receive care[3]*	**Responsiveness of Service** *(clinical standards in place)* Example: time-efficient dispatch protocols	**Responsiveness of Service** *(service time intervals)* *Comprehensive Patient Journey Time Example: activation to handover time	**Morbidity & Mortality**
Equitable *care that does not vary according to gender, ethnicity, geographic location, socioeconomic status[3] or age*	**Accessibility of Service** *(aircraft/ team allocation)* *Cultural awareness & sensitivity Example: Required in-service training	**Patient Disposition** *(discharge status)* *Adaptive Referral System (identify steps; multiple IHT, back-transfer)	**Disparate mortality rates** *Patient, family & community satisfaction and follow-up

*Initiatives identified by the research team as areas in which the published literature does not appear to comment.

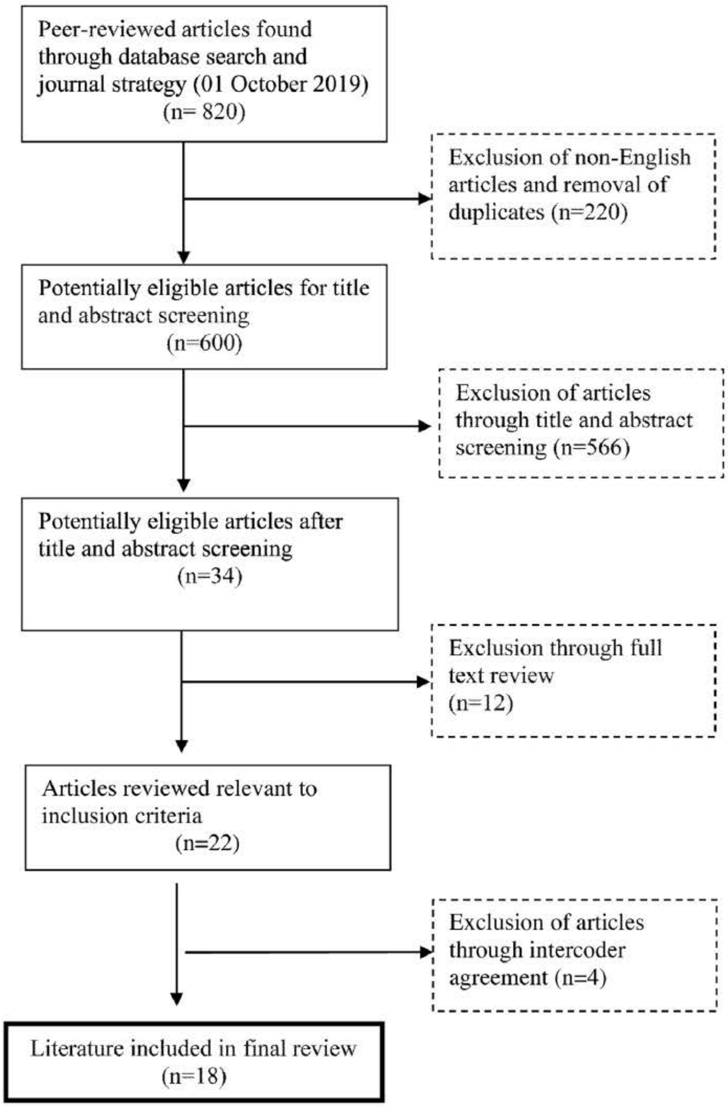

Fig. 1. PRISMA flow diagram.

Results

Eighteen articles were selected for this study; from the initial search of 820 articles, which met the criteria. After removal of 220 non-English articles and duplicates, 600 articles were initially assessed for relevance by one author (KE) by title and abstract utilizing color-coded spreadsheet columns "yes", "no" or "maybe" resulting in the exclusion of a further 566 articles. Full-text assessment of relevance and significance was then completed of the remaining 34 articles, resulting in the removal of a further 12 articles, with 22 remaining. Second author (MTE) assessed the categories, removing 4 'maybe' articles, resulting in final inclusion of 18 articles (Fig. 1). There was no need to contact authors of selected articles for content queries. Risk of bias was appraised by three authors; one piloting (KHE) and two have previous risk of bias assessment experience (MTE, RF). Three authors have domain and content expertise (KHE,GF,RF), one with current clinical expertise (MTE). Disagreement was discussed between reviewers (KHE and MTE) until consensus was reached. It was not necessary to contact authors for more information. Answers to signalling questions are "yes", "probably yes" (low concerns), "probably no", "no" (higher concern), and "no information" (unclear). Table legend includes visual colour and symbols for transparent translation (Appendix D). Of the eighteen papers include in the study, all met the study eligibility criteria. One paper had unclear risk of selection of studies, due to inadequate methods description. Seven papers had unclear risks of data collection and study appraisal due to inadequate or lack of methods description. However, six papers had high concern for synthesis and findings due to absent or inadequate methodology. The third phase, risk of bias in the review, had two papers with high concern, due to unidentified synthesis process and comparator data with a ten-year gap difference.

Phase 1: The range and nature of outcome measures in the selected studies

The eighteen selected studies have been categorized into four main areas which explore the study's nature and focus; interventions, comparisions, primary and secondary outcome measures and independent variables that measure the outcome (Table 1). Additional results tables are included; 'Overall summary selected article/ study design/ data source/ participants/ source of funding' (Appendix F) and 'Overall study characteristics summary' (Appendix G).

Phase 2: Content analysis themes and coding of outcome measures

Guided by a qualitative content analysis approach, words and phrases were extracted from each of the eighteen studies' primary, secondary outcome measures and independent variables. Examples of these words and phrases include,' mortality rates', 'ICU admission', 'GCS at admission', 'prehospital time' and 'discharge home, jail, psychiatric facility, rehab or AMA'. Colour-coding of each variable provided a beneficial visual guide. Twenty unique codes emerged; survival, death, functional independence measures, quality of life, retrieval type, provider mix, mission type, scene survey, interventions, scene assessment, patient destination, distance/location of definitive care, patient treatment/management, aircraft/ team allocation, aircraft/ team utilization, clinical standards in place, compliance of clinical standards, service time intervals, discharge status, length of healthcare episode. These twenty codes were grouped into eight larger themes; asset/ team type, access to definitive interventions, prehospital factors, mortality, morbidity, responsiveness of service, accessibility of service and patient disposition. For example, the independent variable, 'Glasgow Coma Scale (GCS)' was used in eight of the selected articles to identify scene assessment [26–28,30,31,34,35,37]. Moreover, the scene assessement code can be grouped into a larger cluster theme of 'Prehospital factors' (Appendix E).

Phase 3: Selected study performance theme effects- similarities and differences within six Institutes of Medicine (IOM) and three Donabedian domains

To highlight performance measure similarities and differences, the eight key performance themes that emerged in Phase 2 are capitalized and italicized here in Phase 3. Performance themes may articulate in multiple IOM domains simultaneously. For example, the theme *Asset/ team type* was used by the authors to measure the performance of nurses, doctors or paramedics providing evidence based care for those that can benefit (IOM *Effective*), and also the performance of helicopters which avoid wasted time, equipment, energy or supplies (IOM *Efficient*). Therefore, *Asset/ team type* is appropriately placed in both domains. However, two themes, *Mortality* and *Morbidity* are only appropriate in one Donabedian domain, *Patient Outcome*, as these relate to the physiologic health state of a patient resulting from health care.

Effective

The IOM *Effective* domain focuses on 'providing evidence-based care for those that can benefit, refraining from services to those not likely to benefit' [3]. The Donabedian *Structure measure* domain is concerned with the material and human resources of delivering healthcare. Central to the air ambulance service are the people whom dispatch and maintain assets and the flight team. Utilisation of flight nurses, doctors, paramedics and dispatch specialist [22,25,28,31,33,39] emerged in the first theme, *Asset/ Team Type* that provide highly specialised care to ill and injured patients. However, variation in scope of practice, length of training and breadth of experience create a disparity in access to care, if early identification was not provided to patients that could benefit [22–28,33–35,37,39]. Subgroup populations, like paediatric patients, face a disparity in care when treatment choice does not match the need [28]. Consequently, the theme *Access to Definitive Interventions* was predominate in treatment, destination, location and management of critical patients of all selected articles [22–39]. The third theme, *Prehospital Factors*, identified the scene survey, scene assessment and interventions of patients, in fifteen-selected articles [22,23,26–39]. *Mortality*, as a theme related to specific pathology or mechanisms, as cardiovascular-related [22,24], trauma [26,27,29,30,34,35,37–39] or immersion injury [28]. Whereas, the *Morbidity* theme related specifically to neuro-cardiovascular-related [22,24,32], trauma [26,27,34,35,37–39] and immersion injury [28].

Efficient

The second IOM quality domain *Efficient* is healthcare delivery that 'avoids wasting time, equipment, energy or supplies' [3]. The first theme, *Asset/ Team Type* emerged in Garner et al., [28], that concluded discontinuation of an air ambulance service, specific to helicopter speed-designation and physician skill-designation, lead to decrease in service performance [28] (pg. 98). This infers under-triage. On the other hand, Wormer et al. [31], defined overtriage as, "patients are transported by aircraft and discharged from the emergency department or from the facility within 24 hours after arrival" (pg. 93). Both under- and over-triage, are examples of inefficient delivery of care and a waste of both *Asset and Team Types*. A health service that isn't available or mismatched for the patient, it becomes inefficient and wasteful [3]. For this reason, non-compliance of clinical standards in prolonged time intervals (e.g., dispatch-activation, facility arrival-departure) [22,25,32,33,36], and mission mismatch (e.g., scene direct to a trauma facility vs. interhospital transfer to trauma facility) [24,26,33] was a theme for *Responsiveness of Service*.

Safe

Next, the IOM domain, *Safety* is 'avoiding injury, further loss of tissue or deterioration' [3]. The theme, *Responsiveness of Service* related to helicopters use to assist high acuity, deteriorating patients was a *Process measure* in all articles [22–39]. The clinical standard compliance regarding intubation prevalence was used as a *Process measure* in five articles [26–28,30,35]. *Process measures* which guide compliance of clinical standards in dispatch, activation, and/or facility designation was present in all eighteen articles [22–39]. *Mortality* and *Morbidity* themes were used to identify further loss of tissue or deterioration in immersion injury [28], neuro-cardiovascular-related [22,24,32], trauma [26,27,29,30,34,35,37–39], and early identification that avoided further injury [22,27,28,33–35,37,39].

Patient-centered

The IOM domain, *Patient-centered* is 'respectful and responsive to patient preferences, needs and values' [3]. The design of the air ambulance system is uniquely *Patient-Centered*. One aircraft, one or more healthcare providers, crew, pilot, and several dispatchers facilitate patient-specific needs. Thirteen articles highlight the *Patient-centered* predisposition for the second performance theme, *Accessibility of Service*, regarding the risk ratio of survival with HEMS [22–24,26–30,34,35,37–39]. Services may mismatch the patients' urgent treatment needs and preferences which was discussed in sixteen articles [22–24,26–35,37–39]. *Patient-Centered* care is the focus in *Patient Outcome measures, Mortality* and *Morbidity* [22,24,26,27,29,30,32,34,35,37–39]. The theme, *Access to Definitive Interventions* as a *Process Measure* used distance to measure outcome variation in treatment and health management, due to the physical distance from care [22,23,27,29,31,32,35]. In addition, rural dispatch for the geographic disparities for patients in these locations and variations between men and women [23,27,31,35].

Timely

IOM define *Timely*, as 'reducing waiting and delays for those that give and receive care' [3]. In the studies, the theme, *Responsiveness of service* reported helicopters had three advantages when comparing ground ambulance alternatives. The first advantage was the designation of faster transportation time [22–25,27,29,31–34,36,39]. Yet, those *Timely* advantages disappear when patients live beyond the helicopters' range. Under these circumstances, the delay in receiving treatment was a considerable disadvantage [22–24,26,35]. A second *Timely* advantage in the *Responsiveness of Service* theme was assigning clinical crews' high levels of training and experience, related to early identification of patient pathology [22,26–28,30,33–35,37–39]. A third *Timely* advantage was the result of established dispatch and activation protocols [25,28,29,31,33]. However, a disparity in *Responsiveness of Service*, was identified when prolonged treatment time negatively effects urgent cardiac, trauma and stroke patients [22–25,27,29,31–34,36,39]. The *Patient Outcome measure* are *Mortality* and *Morbidity* [22,24,26,27,29,30,32,34,35,37–39].

Equitable

The final IOM quality measure, *Equitable*, 'care that does not vary according to gender, ethnicity, geographic location, socioeconomic status or age' [3] was used by all eighteen authors [22–39]. Helicopter assets benefit patients, largely due to the light and agile rotor-wing design. The *Accessibility of Service* theme focus on helicopters allocation in ten articles [22–24,26,30–32,34–36], and compared to ground ambulances in eight articles [22–24,27,30,32,34,37]. However, there are limits to the helicopter design; one is its relatively small fuel-carrying capacity. This trade-off means a short flight time/distance range of approximately 250 kilometres. Rural patients in these selected articles, who were outside of this range, were not able to benefit from helicopters' speed and agility. This *Accessibility of Service* disparity in access to care, was evident in six articles that healthcare delivery varied due to rurality [22,23,31,32,35,36]. Patient length of stay in hospital [26,31,34,35] and facility where they dispositioned or discharged [27,30,32,34,35,37,38], was a theme *Patient Disposition* in Donabedian *Process Measure*.

Phase 4: Content analysis and distribution to create a strategic quality framework

The fourth phase distilled the performance measure content from the main themes (Appendix E), integrated the combined IOM and Donabedian quality format to create a strategic quality framework (Table 2). Seven gaps emerged in the framework that ordinarily require performance evaluation; patient comfort and satisfaction reporting, cultural awareness training, safety alarms in place to identify volume stress, optimal coordination of resources, cost of service analysis, total system response time and the comprehensive patient journey analysis. These gaps are explored further in the discussion section.

Discussion

This review found eighteen articles which explored the range and scope of performance measures of air ambulance services. A quality framework was produced to help air ambulance services measure their performance. There are a number of key issues that impact performance measurement that we will discuss; using mortality as a sole measure, identifying service thresholds, limitations of registry data and analysing the whole patient journey.

Measuring mortality alone has limitations

Life and death are arguably, the most important outcome measures. However, measures of quality emergency systems, based solely on patient mortality may be a poor indicator, due to the nature of trauma and life-threating urgency [43]. The IOM warn against the sole use of mortality as it may be a measure of ease, rather than a measure of quality [3]. People die for a variety of different reasons; some of which have little to do with service effectiveness [43]. Focusing on mortality as a sole measure implies that successful emergency interventions are not clinically important, if a patient does not survive, e.g., rapid sequence intubation. Furthermore, mortality, as a sole measure for quality care, may not account for underlying chronic illness and morbidity [18]. Therefore, it is relevant to include measures like patient comfort, satisfaction and cost of service in the framework.

Data utilisation to raise an alarm

Unintentional data errors or intentional manipulation of data may be present in administrative databases, i.e., altering time-stamped events to acceptable ranges [44]. Valuable data may also be excluded, i.e., died in flight or on tarmac, cancelled flights in route, or discoordination waiting for connecting ground transport. Accordingly, none of the eighteen selected articles used common healthcare performance indicators, 'adverse event', 'near misses' or 'error', as safety-specific measures. This gap was perplexing, as current aviation and medical reporting standards have built a requisite culture of safety [42], from a history of fatal accidents to crew and patients [42]. As a result, risk mitigation and 'Safety-First' are woven into every aspect of the service. The lack of adverse event reporting may be due in part, to patient privacy and confidentially, maintaining balance between disclosure and community trust, crew non-disclosure, and in part to a competitive, corporate marketplace. Therefore, we propose a surrogate measure which may signal 'pre-threshold alarms', in lieu of adverse event reporting [45]. Pre-threshold alarms would identify upward utility trends in regional referral patterns that may indicate volume stress and put pressure on safe, appropriate, early intervention and transfers.

Data source

Service performance data are available from a variety of sources. Trauma registries have limitations in the prehospital and retrieval events, due to significant variations of key registry variables and their definitions [46]. Linking health databases, such as administrative and clinical data, with hospital data and the death registry, can enable epidemiological monitoring, surveillance, analytical assessment & prospective modelling of aeromedical populations [47]. Data linkage can thereby improve patient care coordination and system-wide communication and yield accurate planning & service delivery [47]. Yet, a warning exists; linking patient data without a common unique identifier relies on less rigorous probabilistic methods. Therefore, linking health databases with a common unique identifier and transparent methodology, will create a comprehensive picture of the patient journey, patient outcomes and of the service provided at each step; furthering capacity in understanding the patient experience.

Novel approaches to describe the complex patient journey

Performance measurement needs to incorporate new outcome and process insights. The learning health system [49] is a dynamic, adaptive approach toward new evidence development and application. It is from this understanding; the authors introduce two novel approaches. First, an *Adaptive Referral System* (ARS). This application incorporates the linear emergency care system (one-way toward higher levels of definitive care) and expands it to include the 'reverse flow'; those patients and resources which are going back to a lower level of care but involve the emergency care system. Air ambulance back-transfers (e.g., referring step-down care from tertiary care to regional hospitals) can optimize time and cost efficiency in an otherwise empty aircraft. However, at a certain point, the aircraft are no longer available for its intended emergency purpose. Initiating a patient back-transfer, may inadvertently take an emergency resource out of circulation at a critical time of need. Yet, back-transfer mission types are not included in any of the selected studies. Moreover, interhospital and back-transfer missions may enter the hospital system through the emergency department instead of direct transfer to medical, surgical or rehabilitation care. This unintended consequence may shift resources (e.g., staff, ED beds, equipment) from their intended emergency purpose. Despite this shift, none of the selected studies describes the patient link "back" through the hospital system in an ARS approach. Secondly, individual patient stories and experiences can be difficult to filter due to the large data 'noise' at systems-level assessments. For example, patients in remote regions of Australia may require several assets; boats, ground transport, fixed or rotor-wing aircraft, through multiple facilities, to reach definitive care. However, application of *Comprehensive Patient Journey Time* (CPJT) will calculate air ambulance total system response time (activation-to-handover at receiving facility) and complete utilisation of healthcare services; ED admission through hospital discharge, will add a layer of understanding to their journey. Furthermore, understanding regional retrieval patterns and CPJT trends may help improve patient care by mapping and tracking equitable distribution of resources and equitable access to healthcare. This detail may assist development of education and staffing models in the emergency department and retrieval service and positively influence patient quality care. These two novel learning hospital system approaches (ARS & CPJT) fill performance analysis gaps and are included in the framework. These shifts help to identify the factors that may inform quality valuation and therefore help moderate the aberrant unidimensional influence of a singular approach.

The Framework

Our proposed framework builds upon established core quality criteria, which is measurable, meaningful and manageable. In a dynamic, healthcare context, the framework provides structure to accommodate specific aspects of air ambulance service delivery: disease-specific, transport-specific, process-specific and/or time interval-specific evaluation. The structure also highlight seven gaps, from the authors' perspective, and allows for recommendations; patient comfort and satisfaction reporting, cultural awareness training, safety alarms in place to identify volume stress, optimal coordination of resources, cost of service analysis, total system response time and the comprehensive patient journey analysis. Notwithstanding these gaps, there is reasonable consistency in many of the measures used and mapped against the proposed quality framework. The value and utility of the content analysis and the framework more broadly, will be further tested in subsequent elements of this research program through consultation with additional expertise and in the testing of this framework against actual performance criteria in an air ambulance service.

Strengths and Limitations

This review has limitations is its scope, due to the considerable heterogeneous structures and processes in air ambulance systems. Bias may also be present in the selection phase. However, bias mitigation was improved by employing two methods. First, transparency in the evaluation process. Our protocol paper was published to widen the avenues for transparency and replicability [17]. Secondly, utilizing cognitive reconstruction [40], by collecting outcome measures at the start, then working backward to try to connect effect links leading to the outcome. Risk of bias (ROB) was evaluated (Appendix D) and found several unclear and high risk articles that may impact the review. With this in mind, the authors carefully planned and published the protocol [17] with an appropriate ROB tool[21] to minimise adverse results. Finally, to ensure that all articles of relevance were found, the MeSH term 'air ambulance' was intentionally chosen for the search strategy. This term includes helicopter and fixed-wing assets that are explicitly stated as key words, but also implied main article themes (Appendix C). However, a MeSH indexed strategy may have missed non-indexed articles. Nonetheless, this scoping review contained articles across many acronyms and definitions of transport (e.g., PHEMS, HEMS, helicopter, helicopter trauma team). Further, the use of PRISMA-ScR guidelines minimises the impact of non-indexed articles. There is a need for continued research in these areas, as the service quality, volume and delivery models will evolve over time and we gain a greater understanding of the impact of air ambulance outcomes and process assessments.

Conclusion

There are increasing challenges to the delivery of quality care in air ambulance services. Improvement strategies can strengthen patient care and satisfaction. From this perspective, we have provided a framework to conceptualize quality and focus improvement efforts. Eight outcome measures were created in the framework; asset/ team type, access to definitive interventions, prehospital factors, mortality, morbidity, responsiveness of service, accessibility of service and patient disposition. Yet, seven gaps were identified, which ordinarily require performance evaluation; patient comfort and satisfaction reporting, cultural awareness training, safety alarms to identify volume stress, optimal coordination of resources, cost of service analysis, comprehensive patient journey time and an adaptive referral system analysis. We hope that the development of the framework will encourage discussion to support policy development, strategic service improvement and improve patient outcomes.

Author contributions

All authors were responsible for the concept, development and design of the study. KE and MTE was responsible for the data interpretation. KE takes responsibility for drafts, reviews provided by all authors.

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Disclosure statement

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Declarations of conflict of interests

MTE is employed by LifeFlight Retrieval Medicine Australia. Authors KHE, GF and RCF declare that they have no competing interests.

Appendix A. Search Strategy Database Outcomes in Detail

Database	Search Strategy Boolean/Phrase	Number of Initial Results
Medline Ovid	("patient transfer") AND ("patient outcome") AND (LIMIT-TO (LANGUAGE, Ënglisḧ))	#97
Scopus	(äir ambulancë) AND ("patient outcome") AND (LIMIT-TO (LANGUAGE, Ënglisḧ))	#304
CINAHL	("outcomes (health care)") AND (Air ambulance") AND (LANGUAGE, Ënglisḧ))	#16
PubMed	("Air ambulance[MeSH]") AND ("Outcome and process assessment (health care) [MeSH]")	#294
Cochrane Reviews	("Air ambulance[MeSH]") AND ("Outcome and process assessment (health care) [MeSH]")	#0
Complimentary Search		
Air Medical Journal	("air ambulance") [All Fields] AND ("patient outcome") [All Fields] ISSN:(0167-991X)Air Medical Journal Elsevier site	#80
Emergency Medicine Australasia	("air ambulance") [All Fields] AND ("patient outcome") [All Fields] ISSN:(1742-6731) Emergency Medicine Australasia Wiley journal site	#14
Annals of Emergency Medicine	("air ambulance") [All Fields] AND ("patient outcome") [All Fields] Annals of Emergency Medicine Elsevier site	#15

Appendix B. Search Strategy Rounds in Detail

Round	Query	Items found
#1	Search Öutcome Assessment (Health Care)[̈MeSH]	904740
#2	Search (Öutcome Assessment (Health Care)[̈MeSH]) AND Äir Ambulances[̈MeSH]	257
#3	Search Öutcome and Process Assessment (Health Care)[̈MeSH]	930417
#4	Search p̈atient outcomes[̈MeSH Major Topic]	0
#5	Search Äir Ambulances[̈MeSH]	2385
#6	Search (Äir Ambulances[̈MeSH]) AND P̈atient Outcome Assessment[̈MeSH]	3
#7	Search P̈atient Outcome Assessment[̈MeSH]	4516
#8	Search p̈atient outcomes[MeSH Terms]	0
#9	Search (Äir Ambulances[̈MeSH]) AND patient outcome	371
#10	Search (Äir Ambulances[̈MeSH]) AND (Öutcome and Process Assessment (Health Care)[̈MeSH])	273

Appendix C. MeSH Search Terms and Hierarchy Trees

Outcome and Process Assessment (Health Care): Evaluation procedures that focus on both the outcome or status (OUTCOMES ASSESSMENT) of the patient at the end of an episode of care - presence of symptoms, level of activity, and mortality; and the process (ASSESSMENT, PROCESS) - what is done for the patient diagnostically and therapeutically. Year introduced 1979. Subheadings include classification, economics, epidemiology, ethics, history, legislation and jurisprudence, methods, mortality, organization and administration, psychology, standards, statistics and numerical data, and trends.

No filters restricted the MeSH major topics-only PubMed search builder options. Search included topics found below MeSH hierarchy tree (Fig. C1).

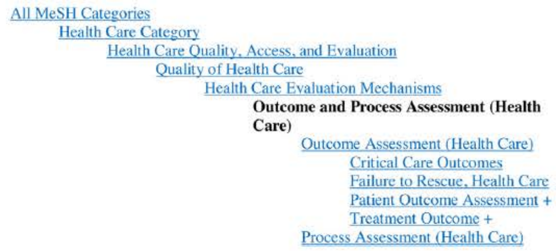

Fig. C1. MeSH hierarchy tree for Outcome and Process Assessment (Health Care).

Air ambulance: Fixed-wing aircraft or helicopters equipped for air transport of patients.

Year introduced 1994. Subheadings include classification, economics, ethics, history, legislation and jurisprudence, organization and administration, standards, statistics and numerical data, supply and distribution, and trends. No filters restricted the MeSH major topics-only PubMed search builder options. No search topics found below MeSH hierarchy tree (Fig. C2).

Fig. C2. MeSH hierarchy tree for Air Ambulance.

Appendix D. Risk of bias in systematic review using ROBIS

Study	Phase 2				Phase 3	Author note
Author	1. Study eligibility criteria	2. Identification and selection of studies	3. Data Collection and study appraisal	4. Synthesis and findings	Risk of bias in the review	Rationale
Ueno, T., et al. 2019[22]	+		?	?	?	Risk that unspecified data type; e.g., clinical, billing, aviation, uncertain in quality
Vaughan Sarrazin, M., et al. 2018[23]	+	+	?	+	?	Risk that data from 2010-2013 are systematically different from published date
Funder, K.S., et al. 2017[24]	+	+	?	+	?	Risk that data from Jan/May2010-April2013 are systematically different from published date
Schneider, M.A., et al. 2017[25]	+	+	?	?	-	Risk that control data from 2007 are systematically different from comparator data
Nolan, B., et al. 2017[26]	+	+	+	-	?	Risk that missing data are systematically different from available data
Brown, J.B., et al. 2016[27]	+	+	+	-	?	Risk that missing data are systematically different from available data
Garner, A.A., et al. 2015[28]	+	+	?	-	?	Small sample size; Risk that missing data are systematically different from available data
Hirshon, J.B., et al. 2015[29]	+	+	+	-	?	Patient "discharged in 24 hours" as a measure of predicted mortality
Hannay, R.S., et al. 2014[30]	+	+	+	-	?	Retrospective and single centre; No separation of Primary flights vs. IHT flights
Wormer, B.A., et al. 2014[31]	+	+	+	-	?	Four data sources without a shared patient identifier
Walcott, B.P., et al. 2011[32]	+	+	+	?	?	HEMS or GEMS transport time not recorded
Reiner-Deitemyer, V., et al. 2011[33]	+	+	+	?	?	Registry data elements not included
Brown, J.B., et al. 2011[34]	+	+	+	?	?	Regional variation bias uncertain in dispatch criteria
McCowan, C.L., et al. 2008[35]	+	+	+	?	?	Synthesis methodology not identified in rural and urban GEMS
Konstantopoulos, W.M., et al. 2007[36]	+	+	+	?	?	HEMS activation data not included
Davis, D.P., et al. 2005[37]	+	+	+	?	?	Risk in bias as age was used as a surrogate for comorbid disease
Akmal, M., et al. 2003[38]	+	+	+	?	?	Risk that missing data are systematically different from available data
Oppe, S., et al. 2001[39]	+	?	?	?	-	Synthesis process not identified

TABLE KEY: + = LOW CONCERN, - = HIGH CONCERN, ? = UNCLEAR RISK.

Appendix E. Content analysis themes, coding, outcome measure and independent variable examples

Theme	Codes	Outcome measure and independent variable examples	Selected studies
Mortality	Survival, Mortality	Mortality after admission, Survival to ED discharge	22, 24, 26-30, 34, 35, 37-39
Morbidity rates	Functional Independence Measures, Quality of life	Modified Rankin Scale, Pediatric Cerebral Performance Category	22, 27, 28,33, 39
Asset/ team type	Retrieval type, Provider mix, Mission type	HEMS transport, PHEMS, Scene, modified scene, interfacility transfer	22-24, 26-28, 30, 32-34, 37
Prehospital factors	Interventions, Scene assessment, Scene survey	Anaesthesia induction, Scene VS, Penetrating injury	22, 23, 26-39
Access to definitive interventions	Patient destination, Distance/location of definitive care, Patient treatment/management	Hospital designation, Distance transported, Mechanical Thrombectomy, Thrombolysis, Trauma Center designation	23, 27, 28, 30, 33, 34, 35, 38
Accessibility of service	Aircraft/ team allocation, Aircraft/ team utilization	HEMS crew for pediatric blunt trauma, Helicopter use over time, HEMS utilization for MT, HEMS for moderate to severe traumatic head injury	22-24, 26-35, 37, 39
Responsiveness of service	Clinical standards in place, Compliance of clinical standards, Service time intervals	Activation-to-scene time, Symptom onset to stroke center arrival, Time from onset to reaching hospital, Average distance and time of flight	22, 25, 27, 28, 31-35, 37, 39
Patient disposition	Discharge status, Length of healthcare episode	Discharge home, jail, psychiatric facility, rehab or AMA, ICU length of stay	26, 27, 29-31, 34, 35, 37, 38

Appendix F. Overall summary selected article/ study design/ data source/ participants/source of funding in chronologic, descending order

Author, publication date	Title of article	Study Design	Data Source(s)	Participants	Source of funding
Ueno et al. 2019 [22]	Helicopter transport for patient with cerebral infarction in rural Japan	Retrospective, observational cohort	Not stated	546	Not reported by study authors
Vaughan Sarrazin et al. 2019 [23]	Disparities in inter-hospital helicopter transportation for Hispanics by geographic region: A treat to fairness in the era of thrombectomy	Retrospective cohort	United States Medicare claims from Centers for Medicare and Medicaid Services (CMS), and CMS Beneficiary Enrollment	8027	Agency for Healthcare Research and Quality
Funder et al. 2017 [24]	The impact of a physician-staffed helicopter on outcome in patients admitted to a stroke unit: A prospective observational study	Prospective, observational cohort	The Danish Clinical Registry (The Danish Stroke Registry) and The Danish Civil Registration System	1068	TrygFonden grant
Schneider et al. 2017 [25]	Reducing door-in-door-out intervals in helicopter ST-segment evaluation myocardial infarction interhospital transfers	Retrospective and historical observational cohort	Aeromedical computer-aided dispatch database and referring, receiving hospital records	417	Institutional Clinical and Translational Science Award
Nolan et al. 2017 [26]	Comparison of helicopter emergency medical services transport types and delays on patient outcomes at two level 1 trauma centers	Retrospective, cross-sectional analysis	Local trauma registry	911	Not reported by study authors
Brown et al. 2016 [27]	Geographic variation in outcome benefits of helicopter transport for trauma in the United States: A retrospective cohort study	Retrospective cohort	United States National Trauma Data Base	1,679,675	No funding was received
Garner et al. 2015 [28]	Retrospective evaluation of prehospital triage, presentation, interventions and outcome in paediatric drowning managed by a physician staffed helicopter emergency medical service	Retrospective cohort	PHEMS crew screening or dedicated paramedic in control room or hospital medical notes	42	No funding was received
Hirshon et al. 2015 [29]	Maryland's' helicopter emergency medical services experience from 2001 to 2011: system improvements and patients' outcomes	Retrospective cohort	HEMS computer aided dispatch database (for HEMS usage) and the state trauma registry (for patient outcomes)	37,407	No funding was received
Hannay et al. 2014 [30]	Retrospective review of injury severity, interventions and outcomes among helicopter and nonhelicopter transport patients at a Level 1 urban trauma centre	Retrospective cohort	Hospital trauma registry	14440	Not reported by study authors
Wormer et al. 2014 [31]	Improving overtriage of aeromedical transport in trauma: A regional process improvement initiative	Prognostic cohort	Air transport records, prehospital records, trauma registry and ED admission records	3,349	Not reported by study authors

Author, publication date	Title of article	Study Design	Data Source(s)	Participants	Source of funding
Walcott et al. 2011 [32]	Interfacility helicopter ambulance transport of neurosurgical patients: observations, utilization, and outcomes from a quaternary level care hospital	Retrospective cohort	EMR at receiving Level 1 center.	167	Funding support from Harvard Catalyst
Reiner-Deitemyer et al. 2011 [33]	Helicopter transport of stroke patients and its influence on thrombolysis rates	Prospective, observational cohort	Austrian Stroke Unit Registry	905	Not reported by study authors
Brown, J.B., et al. 2010 [34]	Helicopters and the civil trauma system: National utilization patterns demonstrate improved outcomes after traumatic injury	Retrospective cohort	United States National Trauma Data Base v.8	258,387	Not reported by study authors
McCowan et al. 2008 [35]	Outcome of pediatric trauma patients transported from rural and urban scenes	Retrospective chart review	HEMS flight logs, transport records, 3x hospital Level 1 trauma registries.	549	Not reported by study authors
Konstantopoulos et al. 2007 [36]	Helicopter emergency medical services and stroke care regionalization: measuring performance in a maturing system	Retrospective, consecutive case study	Local HEMS and receiving hospital EMR	123	Not reported by study authors
Davis et al. 2005 [37]	The impact of aeromedical response to patients with moderate to severe traumatic brain injury	Retrospective, observational cohort	San Diego County Trauma Registry	10,314	No funding was received
Akmal et al. 2003 [38]	Functional outcome in trauma patients with spinal injury	Retrospective data analysis	HEMS trauma registry; administrative and clinical data	263	No funding was received
Oppe et al. 2001 [39]	The effect of medical care by a helicopter trauma team on the probability of survival and the quality of life of hospitalised victims	Prospective cohort for QoL, retrospective for polytrauma patient data.	Standard forms; 11x ambulance posts, the HTT, 8x hospitals	517	Not reported by study authors

Summary Key: ED-emergency department; EMR-electronic medical records; HEMS-helicopter emergency medical service; PHEMS-physician helicopter emergency medical; QoL-quality of life.

Appendix G. Overall study characteristics summary

Patient Information (n=18)	n (%)	Study Demographics	n (%)	Air Ambulance Service Information	n (%)	Data Information	n (%)
Patient Suspected Pathology		Country Origin of Study		Transport Type		Data Source	
Trauma (TBI, blunt, spinal)	10 (60)	America	11 (65)	RW-only	8 (40)	Stroke or Trauma registry-only	3 (15)
Immersion injury	1 (5)	Canada	1 (5)	RW vs. Ground transport	10 (60)	Electronic medical records-only	1 (5)
STEMI	1 (5)	Japan	1 (5)	Mission Type		Billing/ Claims-only	1 (5)
Neurosurgical (broadly; e.g., TBI, ischemic stroke, spinal injury, intracranial aneurysm)	1 (5)	Britain	1 (5)	Interhospital/ interfacility transfer	4 (20)	Mix of registry, administrative, clinical, aviation	10 (60)
Stroke	5 (25)	Netherlands	1 (5)	Primary/ scene transfer	5 (30)	Not specified	3 (15)
Pre-Selected Patient Age		Australia	1 (5)	Both IHT and Primary	6 (35)	Data Linkage Method	
Paediatric < 16 years	2 (10)	Denmark	1 (5)	Not specified	3 (15)	Common unique identifier statement	1 (5)
Adult > 16	5 (30)	Austria	1 (5)	Crew Configuration		Lack of common unique identifier statement	1 (5)
Both paediatric and adult	5 (30)	Population Density		Paramedic-only	1 (5)	Linkage method not specified	16 (90)
No pre-selection age distinction *Selection pathology may assume age	6 (30)	Rural	1 (5)	Nurse-paramedic	1 (5)	Analysed data collection commencement date	
Patient Sex		Urban	5 (30)	Nurse-doctor	1 (5)	1985-2005	8 (45)
No pre-selected differentiation	18 (100)	Rural vs. urban	4 (20)	Doctor-paramedic	2 (10)	2006-2012	9 (50)
		Not defined	8 (45)	Mixed combinations	5 (30)	2014-2017	1 (5)
				Not specified	8 (45)		

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2.2 Chapter summary

Chapter 2 is a scoping review of air ambulance patient and service outcome measures over a nineteen-year span of the literature. The aim of the review is to document the range and nature of aeromedical outcome measures in the literature and to develop an aeromedical quality framework for reporting aeromedical patient and service outcomes. The search strategy uses two Medical Subject Headings (MeSH) terms, air ambulance, and outcome and process assessment, five databases searches: Medline Ovid, Scopus, CINAHL, PubMed and Cochrane Reviews, and three complimentary searches relevant to air ambulances. Risk of bias is assessed using ROBIS (Risk of Bias in Systematic Reviews). The next chapter outlines the multiple methods used in the thesis.

2.3 Salient points

- An aeromedical quality framework was created by combining six quality domains from the Institutes of Medicine; effective, efficient, safe, patient-centered, timely and equitable and three from Dr. Avedis Donabedian; structural measures, process measures and outcome measures.
- For the purpose of the review, 'patient outcome measure' was used to avoid confusing outcomes relating to healthcare-related activity actioned for, on behalf of, or by the patient (e.g., readmission status or discharge status), as suggested by the Agency for Healthcare Research and Quality (2014).
- The four-phase content analysis found eight consistent outcome measure themes: asset/team type, access to definitive interventions, prehospital factors, mortality, morbidity, responsiveness of service, accessibility of service and patient disposition.
- The study identified seven gaps which ordinarily require performance evaluation: patient comfort and satisfaction reporting, cultural awareness training, safety alarms in place to identify volume stress, optimal coordination of resources, cost of service analysis, comprehensive patient journey time and an adaptive referral system analysis.

Chapter 3. Multiple methods and data linkage methods

Overview of this chapter

This chapter describes the methods used for all four aims of the thesis.

- aim 1: To document the range and nature of aeromedical outcome measures in the literature,
- aim 2: To use the results of aim 1 to develop an aeromedical quality framework and use it for reporting existing aeromedical patient and service outcomes,
- aim 3: To explore aeromedical patients' journeys in Central Queensland using linked data,
- aim 4: To describe rural clinicians' perceptions of the supports and barriers they experience as they request aeromedical retrieval for patients with suspected appendicitis in Central Queensland.

Multiple methods used in this study included: scoping review to document the range and nature of patient outcome measures and performance indicators in the literature since 2001 (Study 1), analysis of linked data as a means to better understand the patient journey (i.e., the integrated, continuum of care that spans multiple settings) (Study 2), specific outcomes of appendicitis patients and the retrieval service (Study 3) and one-on-one interviews with rural clinicians to explore their perceptions of requesting the aeromedical retrieval service (Study 4). This chapter first addresses details relating to data: sources, preparation and cleaning, matching, task types, defining aeromedical episodes, theoretical assumptions, statistical analysis and ethical considerations. Methods relating to the scoping review are introduced in chapter 2 and closes this chapter with a protocol (Publication 2). Figure A summarises the main aims and outputs from the thesis and places chapter 3 in the conceptual layout of the broader thesis relative to other chapters.

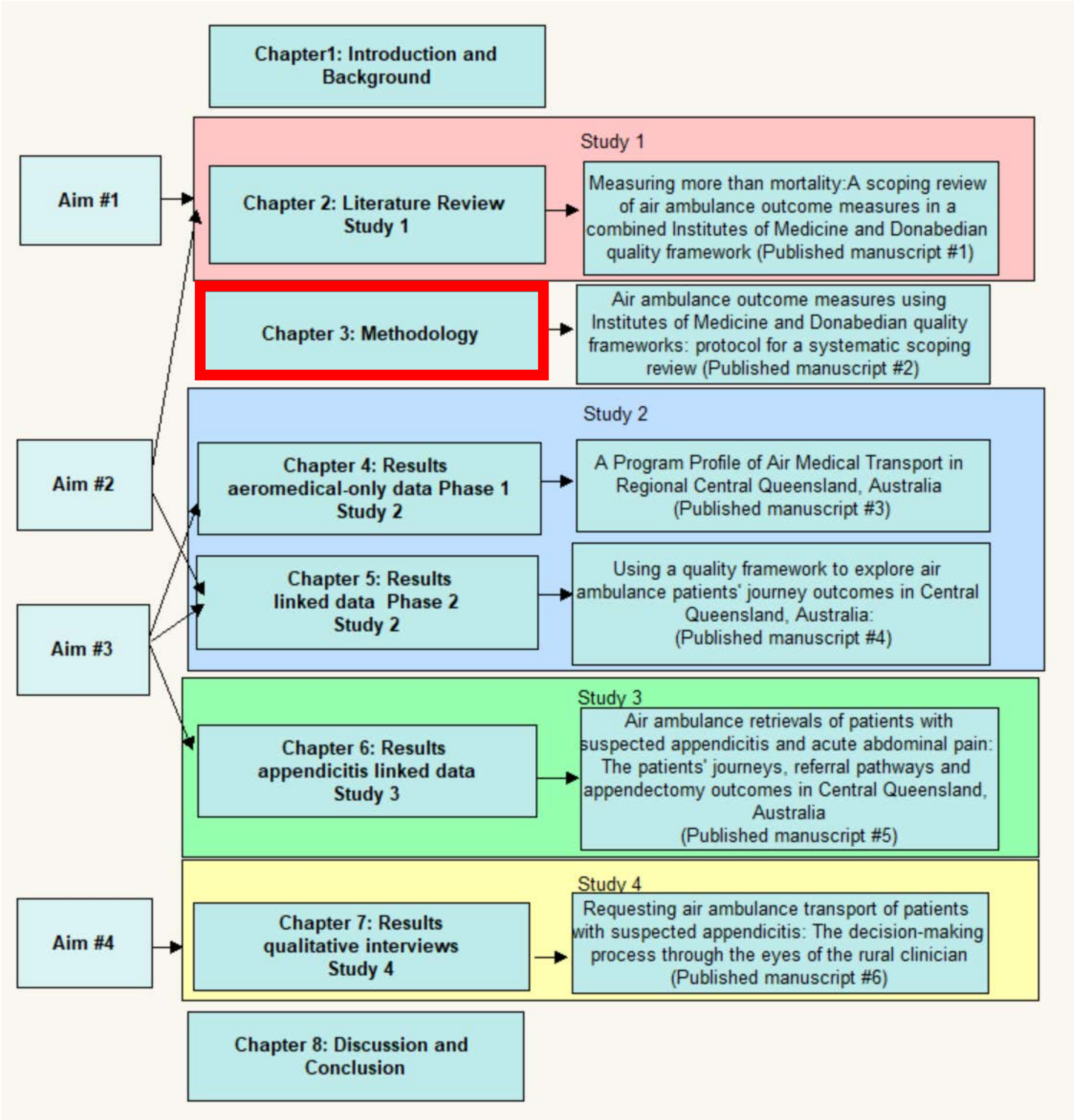

Figure A. Conceptual model of the thesis aims and outputs
Study aims 1-4 are in the boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a red box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

3.1 Multiple methods design

Both qualitative and quantitative methods were used to explore patient and process outcomes from aeromedical retrieval in Central Queensland. A sequential development design[1] (Figure 3.1) used an equal relative level of reliance[1] of both quantitative and qualitative research methods to answer the research questions. The timing of these two methods were sequential; the quantitative data was analysed and interpreted before the qualitative data[2]. The intent was to use results from the qualitative clinician interview findings to provide insights to the quantitative findings. The rationale for using a sequential development[1] multiple methods approach was that the patient and service data described the quantity of retrievals from rural hospitals and clinics, but did not provide understanding about the clinician decision-making process when requesting aeromedical retrievals. The quantitative and qualitative results have been reported in the thesis separately, followed by a final discussion that brings them together to contrast and compare the findings[3].

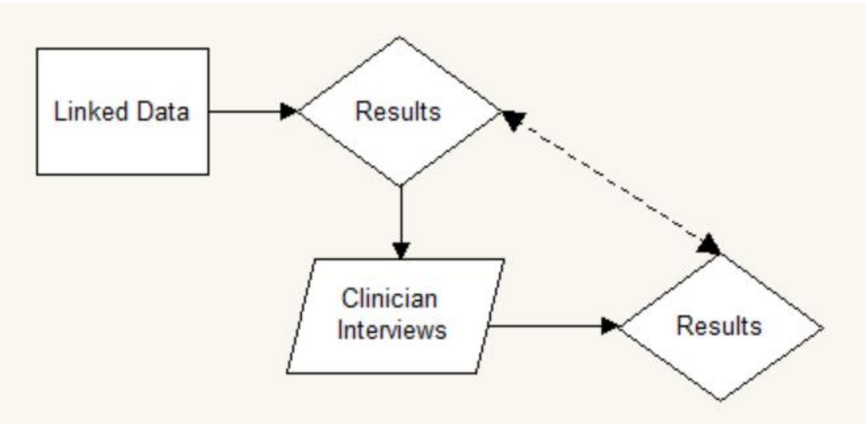

Figure 3.1. PhD candidates' concept of sequential development multiple method research, adapted from Tashakkori and Teddlie (1998)[1]concept of mixed method research.

3.2 Study context and setting

There are three aspects to the study selection in chapters 4-7. The first is the study site (Central Queensland), the second is the study inclusion and exclusion criteria and the third is the focused pathology (appendicitis).

3.2.1. Study site

The Central Queensland Hospital and Health Service (CQHHS) district was chosen as a study site because of the importance of aeromedical services to its operations and its lack of tertiary health services within its political and economic boundary. CQHHS district covers a geographical area of 114,000sq kilometres making land based travel a poor alternative to air travel. Detailed characteristics of the region and the main hospital services are located in chapter 1, section 1.9, maps are located in chapter 5, supplementary file S4 and S5, and short summary characteristics are located in all publications 3-6.

3.2.2 Study inclusion and exclusion criteria

The quantitative studies (Study 2 and 3) inclusion criteria included aeromedical patients flown within the Central Queensland Hospital and Health Service region (CQHHS), from the CQHHS region or into the CQHHS region, who are critically ill or injured of all ages, genders, on either rotor-wing or fixed-wing aircraft, all types of aeromedical tasks (primary, secondary or back-transfers), all types of crew mix (nurse, doctor, paramedic) during the study period 1 January 2010 to 31 December 2014. Exclusion criteria include road transport, commercial flights and Australian Search and Rescue tasks. The qualitative studies (Study 4) inclusion criteria is discussed in detail in chapter 7. The study's inclusion and exclusion were included in all manuscripts 1-6.

3.2.3 Study focused pathology - Appendicitis

Appendicitis was chosen in study 3, based on the high frequency of appendicitis related aeromedical interhospital transfers in CQHHS in study 2. Therefore, its occurrence was explored further. Appendicitis is the most common emergent surgical procedure performed in the world[4]. Undifferentiated abdominal pain is the leading presentation complaint to Australian emergency departments[5] and appendicitis is the most common differential diagnosis in patients that present with abdominal pain[6]. These pathologies present a challenge for rural emergency departments without diagnostic capabilities or local general surgical services[7]. Therefore, rural aeromedical interhospital transfers are common for emergency general surgery consultation. Details of appendicitis The International Classification of Diseases (ICD)[8] coding are discussed in publication 5.

3.3 Investigation of aeromedical-only data

Two aeromedical patient and service data sources were used. These were managed by Retrieval Services Queensland (RSQ) and owned by the state's public health provider Queensland Health. The two sources were: Queensland Neonatal Emergency Transportation Systems (QNETS) (i.e., neonatal and paediatric patient and service data) and Clinical Coordination and Retrieval Information Systems (CCRIS) (i.e., adult patient and service data). Eight variables were included: two event timestamps (request date time and retrieval date), priority status, illness coding, patient age and sex, sending and receiving facility names (details of these variables are discussed in publication 3). However, the investigation of aeromedical retrieval data identified three limitations (Table 3.1). First, aggregated data did not clearly differentiate between interhospital transfer (IHT), step-down, back-transfer, or single-step flights. Second, illness and injury categories did not use The International Classification of Diseases (ICD)[8] coding. Finally, the lack of patient disposition information. To address these limitations, it was proposed that a data linkage approach would help further elucidate information about aeromedical patients and services.

Table 3.1. Limitations of Study 2, which prompted data linkage

Limitation description	Measures required to fill gap
Lack of mission type	Interhospital transfer, single or step-down or back-transfer
Non-specific illness/ injury descriptions	ICD-10-AM categories
Lack of patient disposition information	Emergency department and hospital disposition data

3.4 Linkage of data

The linkage of data built upon the limitations from initial analysis of aeromedical-only data and requested patient and service data to be linked from five additional sources: two air ambulance vendors (service providers), public emergency departments, inpatient public hospital, and death data. The two original data sources were included (CCRIS and QNETS), which brought the total data sources to seven. The following sections detail the steps required to achieve a linked data file.

Queensland Health requires data linkage to be undertaken by the Statistical Service Branch (QHSSB) to maintain a high level of patient confidentiality and data security. QHSSB de-identified all patient data by generating a set of data linkage identification 'keys' that were given to the researcher. These identification 'keys' could not be traced back to patient ID's[9]. The 'keys' became the primary ID number. QHSSB utilised deterministic and/or probabilistic data linkage methods[9]. Probabilistic linkage methods relied on statistical models to estimate the probability that patient data from the different datasets refer to the same patient[9]. Deterministic (or exact match) linkage methods used the patient unique identifiers, such as patient name, address, date of birth, sex[9]. In the event that deterministic linkage method was not possible, probabilistic method was used[9]. The following section contains details of data sources, data preparation and cleaning. Source files were given to the researcher from the respective Queensland Health data custodians.

3.4.1 Data sources

Seven sources were included in the linkage (Table 3.2). These individual files were provided to the researcher following the ethics process (Section 3.7.2). LifeFlight Retrieval Medicine (LRM) and Royal Flying Doctor Service (RFDS) managed and maintained patient and service databases for their administrative, clinical and financial purposes. Data sharing requirements between RSQ and its vendors were contractually regulated[10].

Table 3.2. Phase 2 linkage: Seven data sources

Database	Acronym	Description
Clinical Coordination and Retrieval Information Systems	CCRIS	**CCRISS** is a Retrieval Services Queensland (RSQ) managed database, owned by Queensland Department of Health. It contained adult patient and service data.
Queensland Neonatal Emergency Transportation Systems	QNETS	**QNETS** is a Retrieval Services Queensland (RSQ) managed database, owned by the Queensland Department of Health. It contained neonatal, paediatric and high-risk obstetric patient and service data.
LifeFlight Retrieval Medicine Australia	LRM	**LRM** is a company listed in the Australian Charities and Not-for-profits Commission. LRM managed and maintained patient and aviation records for administrative purposes. The data sharing between RSQ and LRM was contractually regulated. Data detailed medical doctor interventions on both rotor and fixed wing aircraft. LRM rotor-wing nurse providers were introduced for the Brisbane metro area in June 2015.
Royal Flying Doctor Service Queensland	RFDS	**RFDS** is a company listed in the Australian Charities and Not-for-profits Commission. RFDS manage and maintain patient and aviation records for administrative purposes. The data sharing between RSQ and RFDS was contractually regulated. Data detailed RFDS nurse interventions on RFDS fixed wing aircraft for interhospital transfers.
Emergency Department Information Systems	EDIS	**EDIS** contained patient-level demographic and clinical information related to acute care emergency hospital admissions. Owned and managed by Queensland Department of Health in public hospitals. EDIS data is permanently linked to QHAPDC and death data by QHSSB.
Queensland Hospital Admitted Patient Data Collection	QHAPDC	**QHAPDC** contained patient-level demographic and clinical information related to hospital admissions. This database was owned and managed by Queensland Department of Health in public hospitals and includes predetermined data from private hospitals. QHAPDC data is permanently linked to EDIS and death data by QHSSB.
Queensland Death Registry	Death	**Death** contained patient-level demographic and clinical information related to patient death. The database was owned and managed by Queensland Department of Health. Death data is permanently linked to EDIS and QHAPDC data by QHSSB.

Seven separate files contained de-identified patient and service data. These individual files were provided to the researcher. A summary of the contents of these files are listed

(Table 3.3). A complete list and description of all variables are located in Appendix B. Records with missing data >85% were removed and not used in the analysis (Appendix B). At the commencement of Phase 2 of this study, the RSQ, LRM, RFDS data were independent and not linked to other data sources in Queensland Health[11].

Table 3.3. Seven sources and summary of contents (Phase 2 linkage)

Data Source	Contents: Rows and columns
CCRIS	13,103 episodes, 23 variables
QNETS	2,766 episodes, 23 variables
LRM	2,087 episodes, 126 variables
RFDS	15,362 episodes, 98 variables
EDIS	363,067 episodes, 28 variables
QHAPDC	703,836 episodes, 15 variables
death registry	12,078 episodes, 8 variables

3.4.2 Data cleaning and preparation

Data cleaning and preparation was performed using R software (2019-07-05; version 3.6.1, The R Foundation for Statistical Computing) and Microsoft Excel (Professional Plus 2016; Microsoft Corporation, Redmond, WA, USA). Data cleaning included three steps:

1.) The documentation and removal of duplicate episodes;

2.) Dates formatted to date and time (hence labelled 'datetime'): dd/mm/yyyy hh:mm;

3.) Data rows in which > 85% of data fields had missing values were documented and removed.

Data preparation included three steps:

1.) Values for patient age and for patient sex, shared among EDIS, QHAPDC, QNETS and CCRIS sources were each merged into one variable. Sex/ gender was converted from numeral format (0,1) to females, males;

2.) CCRIS, QNETS and LRM included records of advice calls to the service and which did not involve an activation of service. Therefore, advice calls along with cancelled tasks and road tasks were removed.

3.) Time errors (e.g., flights that had departure day, month, year or time *after* the arrival date and time) were documented and manually checked. Two hundred and five errors were manually checked, compared to sending, receiving ED, hospital dates and times & corrected (e.g., flight departure in the year 2012, but landed in the year 2002 was corrected to the year 2012) by the PhD candidate and verified for clinical appropriateness by an emergency department consultant and retrieval clinician (Mark T. Edwards MD, Ph.D.) (Table 3.4). Forty-seven percent of time errors came from a midnight date change (e.g., departure date and time was 2 June 2013 at 2300 hours and the arrival was two hours later at 1am, yet the date was still recorded as the 2 June at 0100 hours, instead of the correct 3 June). Eighty-eight percent of errors occurred in the 'Handover' event time (Table 3.4).

Table 3.4. Negative time errors: Type of time error and event time

Characteristic	Result total: 205 #(% in 205)
Type of time errors	
Year error (e.g., depart in 2012, arrive in 2002)	9 (4%)
Month error (e.g., depart in January (01), arrive in November (11))	9 (4%)
Midnight date switch (e.g., begin at 1/1/2011 2355, end at 1/1/2011 0200)	97 (47%)
Day error (e.g., looks like '08' was actually '03')	12 (9%)
One day or several days behind (e.g., depart on 11 June, arrive on 14 June)	22 (11%)
am/pm e.g., (time) change 1400, but recorded 02:00 (for 2pm)	30 (15%)
Error (time) change (e.g., depart at 1400 hours (2pm), but recorded as 0200)	20 (10%)
Day/month switch (Australia records day before month e.g., 2/6=6/2)	2 (1%)

Event time that had the error	
‘Handover’ event time	180 (88%)
‘At scene’ event time	6 (3%)
‘Activated’ event time	10 (5%)
‘First contact’ event time	3 (1.5%)
‘Depart with patient’ event time	1 (0.5%)
‘With patient’ event time	1 (0.5%)
‘Request for service’ event time	1 (0.5%)
‘Arrive at receiving facility’ event time	1 (0.5%)

Next, the QHSSB data linkage primary ‘keys’ were mapped to the patient and service data files.

3.4.3 Mapping primary key to three different identifiers

In Queensland, there is not a unique patient identifier which tracks individuals’ health care, as they moved through the health care system over time. QHAPDC, ED and death data are permanently linked to one another by Queensland Health Statistical Service Branch (QHSSB) and their unique ID’s are exactly similar (Table 3.5). These permanent linkages are collated in a master linkage file (MLF). RFDS documented their data with their own set of patient ID codes. Similarly, CCRIS, QNETS and LRM used their own ID codes, as well.

Table 3.5. Examples of nomenclature for the primary key and three identifiers

Source	Identifier Name	Primary Key Name
CCRIS, QNETS, LRM	Patient_Study_ID	-
RFDS	PATIENTID	-
QHAPDC, ED, death	old_patient_id	
QHSSB	-	new_patient_id

First, the process checked that the identifier mapped at least one primary key, provided by QHSSB. Identifiers which did not, were documented and removed from the file. Secondly, a check was performed to identify if more than one identifier mapped with one primary key (i.e., duplicate records). Any duplicate records were documented and removed. Duplicate records may occur from data entry errors. The file was then ready for the next step to determine the event time links between sources. A summary of Phase 1 and Phase 2 data collection and matching processes is shown (Figure 3.2). The match rate between unique patient identifiers and associated health record was 98.1%, due largely to the inclusion of RFDS and LRM data, coupled with successful data cleaning strategies (Statistical Service Branch file sharing communication). The sheer volume of these two files helped to confirm correct patient identity through deterministic methods; RFDS data file contained 15,362 episodes (see above in Table 3.3) and LRM contained 2,087. Prior to the inclusion of RFDS and LRM, the match rates for patient records between RSQ and QHSSB, averaged 71.2% (Statistical Service Branch file sharing communication). Prior to data cleaning, the match rate was 95.9%. RSQ, RFDS, LRM data are now a part of the MLF, with the help of this study[10].

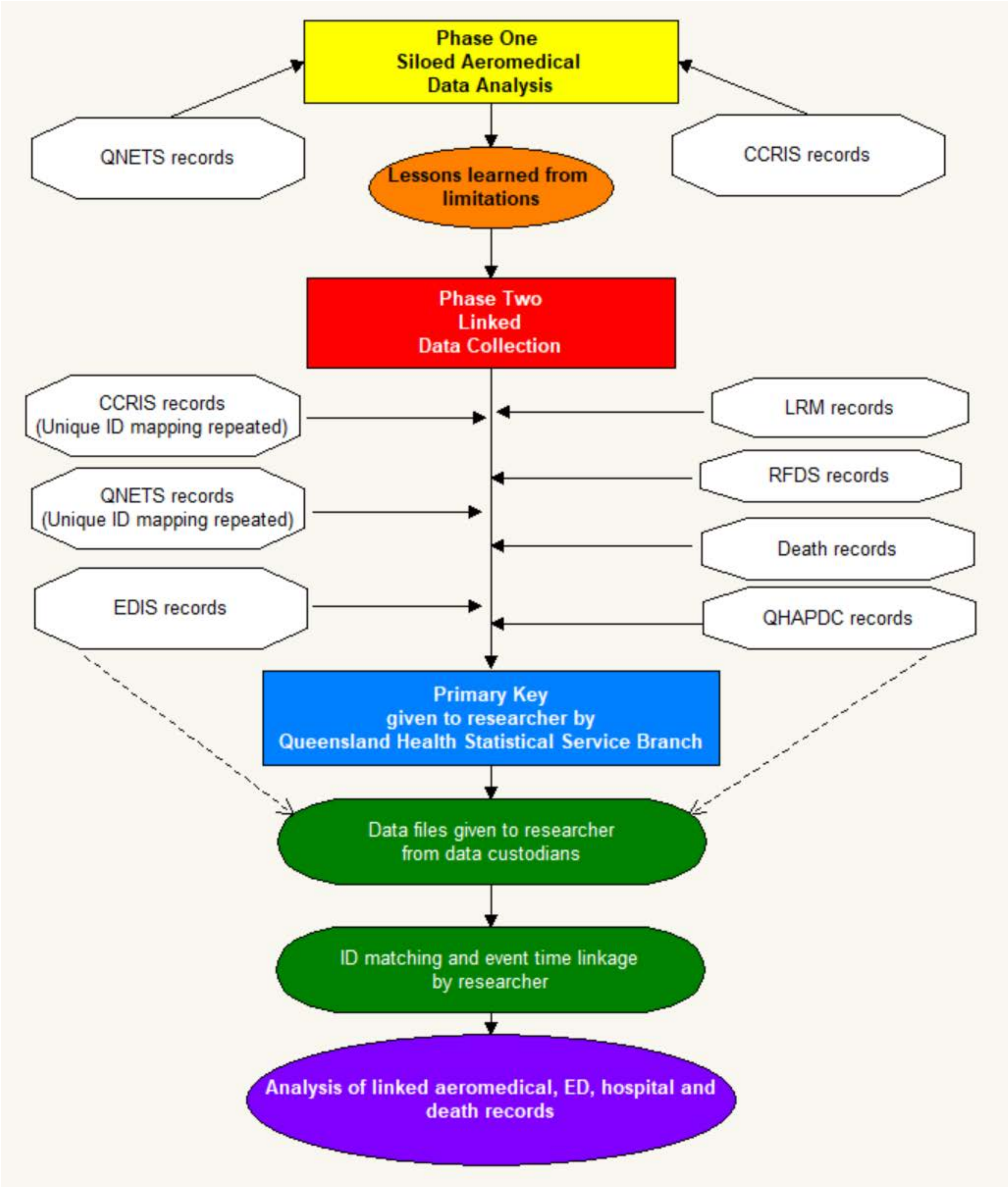

Figure 3.2. Data collection and matching steps: Phase 1 (top, yellow box), lessons learned (orange oval), Phase 2 (red box), primary keys (blue box), ID matching (green boxes) and final analysis (purple oval).

3.4.4 Aeromedical time events

The captured event start times (i.e., timestamps) varied among the four aeromedical sources (*Table 3.6*). The variations were clearly identifiable, when visualized along the task flow path. Understanding the event time variation was vital to correct event matching.

Table 3.6. Aeromedical sources event times, among the typical task sequence

Typical air ambulance task sequence										
request for service	activate team	team depart	land at scene	with patient	depart scene	arrive at receiving facility	handover (clinical)	depart receiving facility	back at base	ready for next task
CCRIS		X	X	X	X	X	X	X	X	X
QNETS		X	X	X	X	X	X	X	X	X
X	RFDS		X		X	X		X	X	X
X*	LRM			X			X			

*LRM data item was >85% missing values and not used for linkage.

Legend	
Available event times	
CCRIS event times	
QNETS event times	
RFDS event times	
LRM event times	
Unavailable event time	X

Initially, CCRIS and QNETS had three event date and times; request for service and activation and date and time of flight. The variable, 'request datetime', identified the date and time a request call was received for aeromedical service. Activation date and time identified activation of medical teams. However, the CCRIS and QNETS datetime of flight was not checked and verified by RSQ[10] for correctness and for this reason it was recommended by RSQ not to be used in the analysis[10]. RFDS provided four datetime stamps. LRM maintained ten datetime stamps. However, the LRM data field which recorded the data and time the retrieval service was requested, ('DATE_RETRIEVAL_REQUESTED') had >85% missing values and was therefore not used for linkage.

Once the aeromedical event times were understood, two composite time variables were created that made the flight event unique and could be linked to events before flight and after flight; 1.) 'start of event time' and 2.) 'end of event time' by combining patient ID and event time:

1.) 'Start of event time' composite:
    a. CCRIS and QNETS was: 'Request Datetime',
    b. LRM and RFDS was: 'ACTIVATION_Datetime',
2.) 'end of event time' composite:
    a. CCRIS and QNETS was: 'Activation Datetime', (as this was the only verified event time),
    b. RFDS was 'DATETIME_HANDOVER',
    c. LRM was: 'ARRIVE_AT_RECIEVING_HOSPITAL_DATETIME'.

Timestamp gaps in data linkage

A time gap was identified between CCRIS and QNETS request time (labelled r1 in Figure 3.3) and the LRM and RFDS activation time (labelled a1 in Figure 3.3). This time gap is identified as Type 1. The maximum gap time identified was 504 hours (twenty one days). A second time gap, Type 2 was identified between request for service (r1 in Figure 3.4) and discharge from hospital (d1 in Figure 3.4).

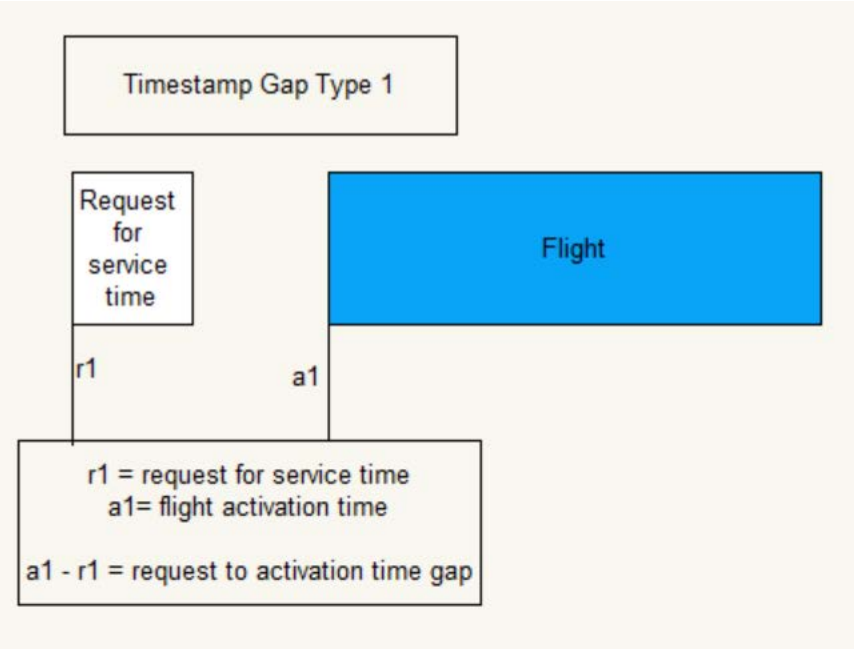

Figure 3.3. Timestamp gap Type 1: between aeromedical 'request for service' event time (r1) and aeromedical 'activation' event time (a1)

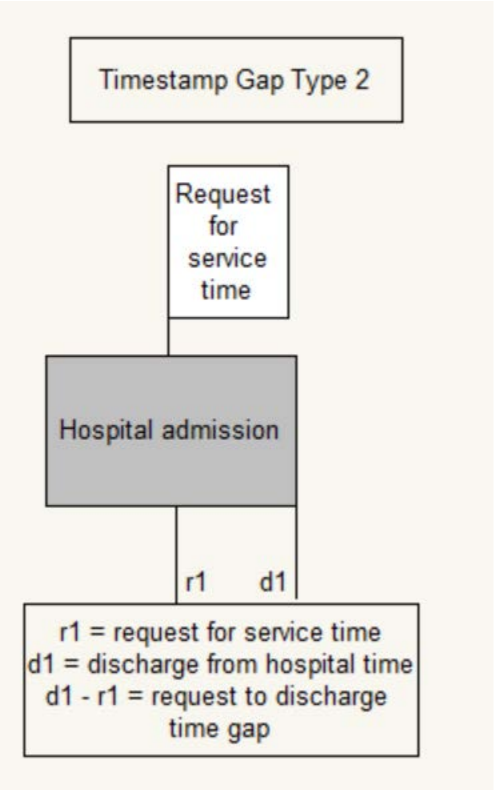

Figure 3.4. Timestamp gap Type 2: between aeromedical 'request for service' event time (r1) and discharge from hospital even time (d1)

3.4.5 Defining an aeromedical episode

Four aeromedical sources (CCRIS, QNETS, LRM and RFDS) provided information (records) about an aeromedical event. In CQHHS, retrieval flights may have a doctor and nurse in attendance for one patient. The doctor information will *only* come from the LRM source. Furthermore, the nurse information will *only* come from RFDS. Therefore, in this scenario, one patient flight will be shared by three records (one from CCRIS requesting service, one from RFDS nurse and one from LRM doctor). These shared records were grouped together. These combined records formed one aeromedical episode. For example, if one patient flew from Rockhampton to Brisbane with one LRM doctor and one RFDS nurse, this information will be collected in the CCRIS record, and in the LRM record and also in the RFDS record. That would be three records in total, for one patient on one flight (Figure 3.5).

Contrastingly, QNETS is a specialist team of doctors and nurses that do not come from LRM or RFDS. For example, in a complicated perinatal delivery scenario; a neonate that is under the care of a specialist QNETS team and a mother that requires an LRM doctor, may fly on an RFDS fixed-wing aircraft with an RFDS nurse in attendance. For this scenario, one CCRIS request record, one LRM doctor record, one RFDS nurse record and one QNETS specialist team record are collected. Understanding the aeromedical provider context is necessary, in order to successfully group patient data records together. Without the understanding of how services can interact, each record could mistakenly be counted as separate, simultaneous aeromedical episodes. For example, the largest group of interactions were between CCRIS and RFDS, with shared records for 10,310 aeromedical episodes. The second largest group had 1,317 shared records between CCRIS and LRM. The smallest interaction was one patient episode that shared records from CCRIS, RFDS, LRM and QNETS. Therefore, knowing the provider context and how the records interact is critical.

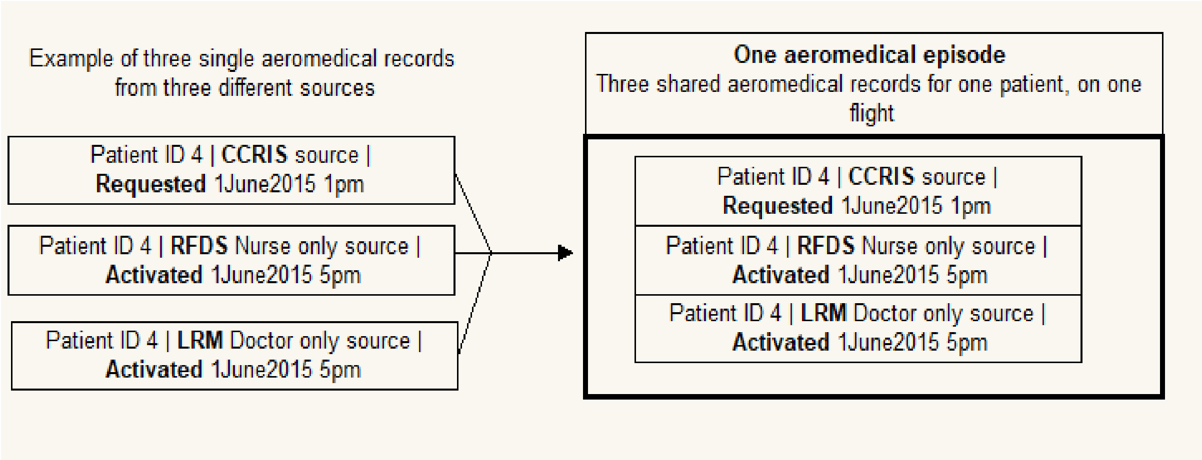

Figure 3.5. Example of single aeromedical records which are shared for one patient on one flight

3.4.6 Mapping aeromedical episodes to hospital, ED and death

Once aeromedical episodes were established for each unique patient identifier, the aeromedical episodes were matched to hospital, emergency department and death records that occurred before and after the flight. Patient death data were provided by QHSSB, but in order to reduce risk of patient identification, only date of death were provided from the Queensland death registry database. Specific times of death were not provided. Therefore, deaths in care during aeromedical transport could not be established.

Similarly to the aeromedical data, a composite variable was created for the ED, hospital and death data:

1.) ‘Start of event time’ composite:
   a. EDIS was: ‘triage_datetime’ and
   b. QHAPDC was: ‘START_DATETIME’.
2.) ‘end of event time’ composite:
   a. EDIS was: ‘phys_depart_datetime’,
   b. QHAPDC was: ‘END_DATETIME’,
   c. Death was: ‘deathdate’.

The emergency department, triage datetime, was the start match and the physical departure was the end match. These were chosen for two reasons. First, the triage datetime had minimal missing values and this timestamp signals the first assessment. Secondly, ED staff may complete discharge entries into EDIS, yet the patient may remain in the department for some amount of time. The time from discharge to departure could be considerable. For example, during the interval of time the retrieval team was preparing the patient for flight or was waiting for ground ambulance transfer to the airport. Therefore, actual physical departure determined the next step in patient care. Datetime events at the beginning of a record of care and the end of care were used to match the subsequent record along the chain of care (Table 3.7). Narrative steps in all of the data linkage processes discussed thus far, have been included to improve study transparency and reproducibility (Appendix B).

Table 3.7. Event time match between sources

Event Time Match			
Field Name	Field Description	Position	Match Sequence(s) *dependent upon patient care pathway
Emergency department (EDIS)			
triage_datetime	Date and time of triage	ED Start	*May match datetime to: Hospital End Aeromedical End
phys_depart_datetime	Physical departure date and time	ED End	*May match datetime to: Hospital Start Aeromedical Start Death End
Hospital (QHAPDC)			
START_DATETIME	start date and time of admission	Hospital Start	*May match datetime to: ED End Aeromedical End
END_DATETIME	end date and time of admission	Hospital End	*May match datetime to: Aeromedical Start Death End
Aeromedical Composite Variables (CCRIS, QNETS, LRM, RFDS)			
DateTime_of_Request	Request for service CCRIS	Aeromedical Start	*May match datetime to: ED End Hospital End
DateTime_of_Request	Request for service QNETS		
DATETIME_ACTIVATION	datetime activation RFDS		
TEAM_ACTIVATED_DATETIME	datetime activation LRM		
DATETIME_HANDOVER	medical team handover RFDS	Aeromedical End	*May match datetime to: Hospital Start ED Start Death End
ARRIVE_AT_RECIEVING_HOSPITAL_DATETIME	arrive at receiving facilityLRM		

Death			
DATE_DEATH	yyyy/mm/dd Date of death	Death End	*May match datetime to: Hospital End ED End

The CCRIS and QNETS request datetime stamps contained 420 (3% of composite variable total) missing data and the Activation datetime had 1,026 (7% of composite variable total) missing values. The RFDS and LRM timestamp links ('handover datetime' and 'arrive at receiving facility datetime' respectively) contained no missing values. The hospital start link, 'start datetime' and end link, 'end datetime' did not contain missing values. The ED start link was triage datetime. There were 9 missing values, <1% of composite variable total). The ED end link was the physical departure of the ED and did not contain any missing values. The death date did not contain missing values. Missing values are found in Appendix B.

3.4.7 Gap from 'handover' event time to start time at receiving hospital

Time gaps were identified between aeromedical handover event time (h1 in Figure 3.6) and hospital start time at receiving hospital (s1 in Figure 3.6). This time gap is identified as Type 3.

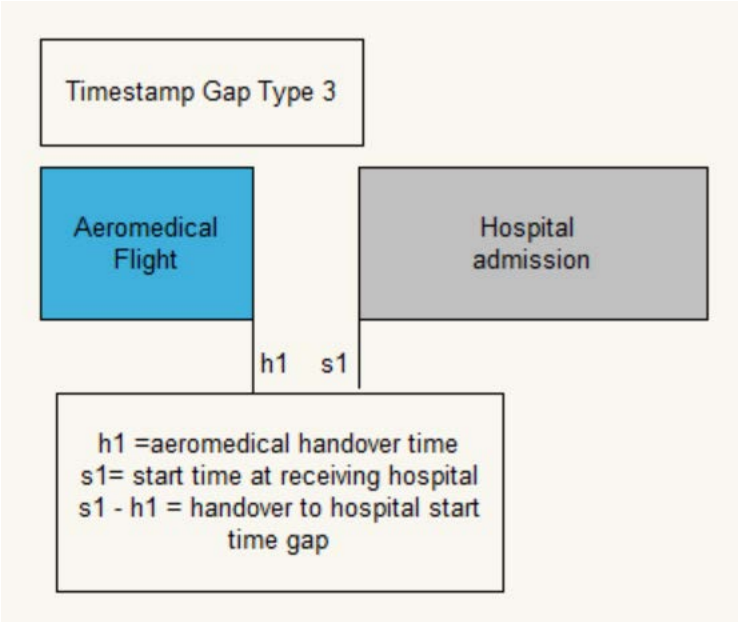

Figure 3.6. Timestamp gap Type 3: between aeromedical 'handover' event time (h1) to start time at receiving hospital (s1)

3.4.8 Determining aeromedical task types

With the data linked before and after flight, three grouped patterns emerged from the data linkage:

1.) There was an absence of any sending facility records *preceding* a flight, but existence of hospital record *following a* flight episode. This group was recorded as a 'Primary' type aeromedical tasking (i.e., retrieved from a roadside accident).

2.) Presence of associated hospital records *preceding* a flight episode, coupled with absence of any facility records *following a* flight. This group was recorded as a 'step-down' or 'back-transfer' tasks where patients return to aged-care or rehabilitation residences.

3.) Presence of different hospital records both *preceding and following* a flight episode. This grouping were recorded as 'interhospital' transfers (IHT) (Figure 3.7). Noting that IHT could occur from lower capacity hospitals toward higher capacity (i.e., rural hospital to tertiary hospital IHT) or from higher capacity toward lower (e.g., back-transfers or step-down care; tertiary hospital to regional hospital IHT).

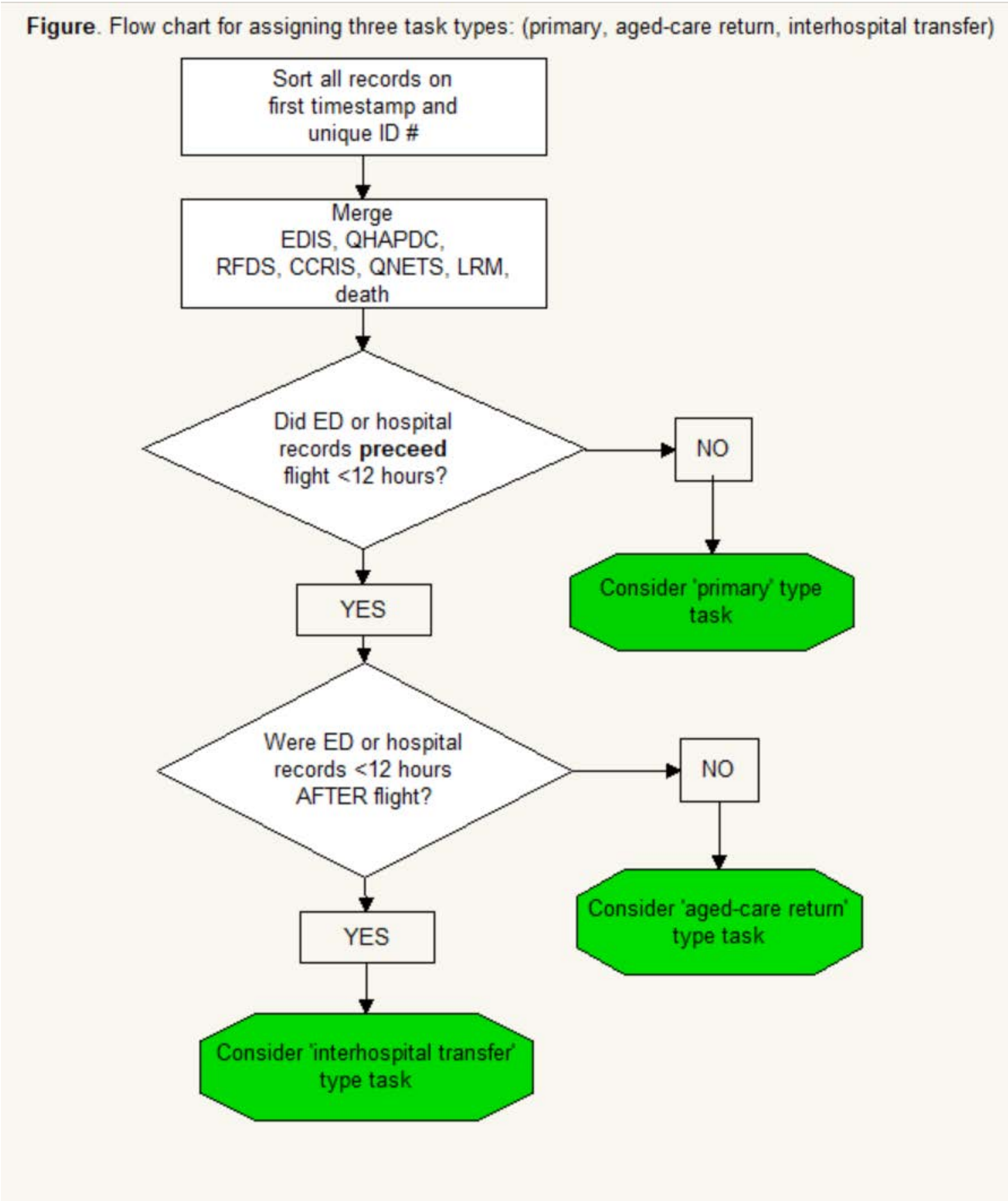

Figure 3.7. Flow chart for assigning three task types: (primary, aged-care return, interhospital transfer)

3.4.9 Creating one linked aeromedical episode

Aeromedical episodes were linked by unique patient ID and time and grouped by task type. The format was changed from a short format (long rows, few columns) to a long format (one row, many columns). This created one linked aeromedical episode for each unique patient ID.

3.4.10 Variable descriptions

Variable descriptions are detailed in chapter 4 publication 3, chapter 5 publication 4, and chapter 6 publication 5.

Patient illness and injury, and diagnosis-related group classification

Methods and table are detailed in chapter 5 publication 4 and chapter 6 publication 5. A full list of AR-DRG (version 7.0) major diagnostic categories (MDC) are located in Appendix E.

Length of ED and hospital stay

Length of ED and hospital stay methods are detailed in chapter 5 publication 4 and chapter 6 publication 5.

Flight priority status

Priority methods and tables are detailed in chapter 4 publication 3 and chapter 5 publication 4.

Regional referral pathways

Regional referral pathway methodology are detailed in chapter 4 publication 3 and chapter 5 publication 4.

Back-transfer or step-down task classification

Back-transfer or step-down task types were not specified in the raw data. To explore back-transfer rates, the origin and destination facility names and locations were used to determine the likelihood that the flight was a back-transfer mission. For example, patients flown from a Brisbane hospital to Emerald Hospital, are grouped as a back-transfer; from higher level of care toward lower level of care.

Accessibility/Remoteness Index of Australia

This study uses the Accessibility/Remoteness Index of Australia (ARIA+)[12], detailed in chapter 5 publication 4.

Aeromedical interval times

Two aeromedical interval times are discussed: 1.) Request for service-to-activation and 2.) Activation-to-handover. The methods detailing these intervals are included in chapter 5 publication 4 and chapter 6 publication 5.

Health service admission pathways

There were two pathways of admission; 1.) Via ED, 2.) Direct hospital admission. The methods detailing these pathways are included in chapter, 5 publication 4 and chapter 6, publication 5.

Statistical analysis

Statistical analysis is detailed in each manuscripts' methods section (publications 2-5).

3.5 Clinician interviews (Study 4)

Clinician interview methods are described in detail in chapter 7 publication 6.

3.6 Theoretical assumptions

My nursing practice in America and Australia, abides within standards of care that focus on critical analysis and thorough evaluation of outcomes[13,14]. It is through my intensive care unit (ICU) nursing experiences, that I perceived and interpreted the aeromedical patient journey as health service provision that is complex[15,16] and interwoven within a regional emergency care system, that functions in a grander Queensland and Australian healthcare system. Through this theoretical lens, I understand that a complex system was woven between multi-discipline health providers, along various levels of service, who make critical decisions throughout a patients' journey. Exploring this complex, air ambulance patient journey phenomena was not possible from one perspective, or one source of data[17]. Data was required from different perspectives[18,19] and sources. Therefore, a sequential development design[3] approach was implemented for quantitative data linkage methods and qualitative clinician interview methods. These multiple methods[3] supported analysis and evaluation which improved understanding of the complex aeromedical patient journey in Central Queensland.

The grand Complex Adaptive System Theory[15] and Systems Theory[16] underpinned this research. Complex Adaptive Theory acknowledged that systems exits within systems[15]. Aeromedical retrieval is not a stand-alone system, but rather functions within a larger emergency medical system, which functions within a state and National healthcare system. An important flexible feature of the theory allowed parts of a system to be studied independently, but its "context matters in fundamental ways"[15]. Each aspect of these theories support improved understanding of the patient journey in Central Queensland.

3.7 Ethical, data security and integrity considerations

The Declaration of Helsinki[20] are thirty-seven ethical principles for research involving human subjects, human material and data. It was established in 1964 by The World Medical

Association and has been amended seven times, most recently in 2013. This study has been conducted in accordance with the Declaration of Helsinki.

3.7.1 Research ethics approvals

The Study 2 Rockhampton data, received ethics approval by The Townsville Health Service District Institutional Ethics Committee (EC00183). The study 2 linked data received ethics approval by Central Queensland Health and Hospital HREC (CQC/16/HREC/8) and Queensland Department of Health (RD007591) for the primary investigator (PI) (KHE), and advisory team (SK, PK, RF, RJ). LifeFlight Retrieval Medicine (LRM) data was provided with their board approval. Also, Royal Flying Doctors Service, Queensland Division (RFDS) data was provided with their board approval. Queensland Health granted permission to waive patient informed consent under the Public Health Act 2005 (PHA). As the data linkage progressed, amendments were submitted to CQHHS HREC. These included day of air ambulance transfer, death registry data coded up to most recent and the inclusion of the PhD candidate's academic advisors. All amendments received institutional approval. Study 4, clinician interviews, received ethics approval by Central Queensland Health and Hospital HREC (CQC/16/HREC/5) and three site-specific approvals were received from Biloela Hospital (Joanne Glover), Emerald Hospital and Blackwater Hospital (Kiran Kinsella). Written consent was received from all participants. Hard-copies of the consent form and the ethics approval were given to each participant. All participation was voluntary and participants were allowed to stop the interview at any time. Prepared semi-structured questions guided the participant, but it no way limited or coerced their responses. Copies of CQHHS HREC and PHA approvals are shown in Appendix D.

3.7.2 Ethics process

Queensland Health Statistical Service Branch facilitated a round table negotiation for study 2, phase 2, between the data custodians of EDIS, Death Registrar, QHAPDC and

Retrieval Services Queensland and the primary investigator (KHE), to raise questions and provide input around the use of their data sets. The custodians agreed upon the research questions and signed support in a Public Health Act. The Central Queensland Hospital and Health Service Ethics Committee agreed to the research methods and signed approval.

3.7.3 Study transparency

Study 2 and study 3 followed a reporting guideline for observational studies in order to increase transparency and quality of the studies[21]. The chosen guideline, 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE)[21] statement identified twenty-two categories for authors to include in their research report. The STROBE[21] checklist is provided in chapter 5 and chapter 6. Study 4 utilised The Consolidated Criteria for Reporting Qualitative Research (COREQ)[22] to structure and report the study (included in chapter 7).

3.7.3.1 Data security and integrity

Data was viewed on either CSIRO or James Cook University owned and maintained devices. Files sent by Queensland Health Statistical Service Branch were sent using time-limited, encrypted passwords. Files sent by QH Retrieval Services Queensland, were sent using separate encrypted passwords. Measures were taken to protect the wholeness and accuracy as data was stored and retrieved. The data was protected as it was stored and retrieved, on James Cook University OneDrive password protected, cloud-based system. The candidate maintained account settings that OneDrive documents sync and upload with desktop edits. The candidate and advisory team (SK, PK, RF, RJ) maintained agreed rules and constraints that data was not altered or edited in the OneDrive online form. OneDrive sent notifications to the candidate, of all views, changes and sharing to downloaded data, that included name of person, date of view/change/share, file size and list of members invited to share data. Version history was maintained in OneDrive, that indicated version number, modification date, modification author name and file size. File naming practices utilized a progressive 'save.point_number and_date' format to identify file changes. Each 'save.point' version file name was included at the start of each weekly update for group reference.

3.8 Scoping review protocol

There is a need to increase transparency and reproducibility of the scoping review[23] especially in aeromedical retrieval as the evidence base is developed. In developing the protocol a conundrum was identified: in the drive to advance medical and aviation service capabilities, we may inadvertently negatively impact future resource sustainability without a plan to identify and evaluate performance indicators. To address this conundrum a quality framework was proposed as a way to explore performance indicators and help inform discussions around the planning and delivery of aeromedical services. The scoping review systematically mapped the range and nature of existing literature in the area of performance indicators, identified existing gaps in knowledge, and synthesized the evidence in a framework, which is presented in protocol format (see publication 2 below). The protocol outlined data sources, search strategy, study selection, data extraction, appraisal of evidence, planned approach to synthesis and analysis. Supplementary materials that were published with the manuscript are listed at the end of the chapter (Supplementary files 3.9) and presented in Appendix B-E.

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Systematic Reviews

PROTOCOL Open Access

Air ambulance outcome measures using Institutes of Medicine and Donabedian quality frameworks: protocol for a systematic scoping review

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Abstract

Background: Dedicated air ambulance services provide a vital link for critically ill and injured patients to higher levels of care. The recent developments of pre-hospital and retrieval medicine create an opportunity for air ambulance providers and policy-makers to utilize a dashboard of quality performance measures to assess service performance. The objective of this scoping systematic review will be to identify and evaluate the range of air ambulance outcome measures reported in the literature and help to construct a quality dashboard based on a healthcare quality framework.

Methods: We will search PubMed, MEDLINE, CINAHL, Scopus, and Cochrane Database of Systematic Reviews (from January 2001 onwards). Complementary searches will be conducted in selected relevant journals. We will include systematic reviews and observational studies (cohort, cross-sectional, interrupted time series) in critically ill or injured patients published in English and focusing on air ambulance delivery and quality measures. Two reviewers will independently screen all citations, full-text articles, and abstract data. The study methodological quality (or bias) will be appraised using appropriate tools. Analysis of the characteristics associated with outcome measure will be mapped and described according to the proposed healthcare quality framework.

Discussion: This review will contribute to the development of an air ambulance quality dashboard designed to combine multiple quality frameworks. Our findings will provide a basis for helping decision-making in health planning and policy.

Systematic review registration: PROSPERO CRD42019144652

Keywords: Air ambulance, Outcome measures, Emergency system, Service delivery, Institutes of Medicine, Donabedian, Quality framework

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Background

Air ambulances, both fixed and rotary wing, have become essential components in modern emergency healthcare systems. Drawing lessons from military conflict, the aim is to use fast transportation means to provide people with acute illnesses and injuries with access to centralized specialist care. The development of modern emegency medicine has provided a further opportunity to enhance the coordination and clinical standards available for the intended purpose of rapid response medical care provided to seriously sick and injured people [1].

However, the implementation of air ambulances are often tested in austere and unfamiliar situations [2–7], using limited and costly resources [8–11], and inequity of time [12, 13], distance [13–15], and accessibility [16–19]. Similar themes have emerged in multiple regions and countries (2:6, 8, 10:13). These developments of improved neurologic, cardiac, and trauma care pathways aim to reduce inequalities and ineffective efforts [8, 11–13, 18]. The increased utilization of air ambulance retrieval and transfers shows no sign of slowing [20, 21] which impacts on an already burdened emergency care system [22–25]. However, the drive to advance medical and aviation capability may tip the balance of future sustainability without a strategic health service plan which identifies and evaluates performance indicators [26]. Quality frameworks can provide structure to explore these indicators and form a basis for discussion. For these reasons, a scoping review was conducted to systematically map the range and nature of existing literature in this area, identify any existing gaps in knowledge [27], and synthesize the evidence in a framework.

The Institutes of Medicine (IOM) quality domains and Donabedian quality attributes are two generally accepted frameworks for health service performance measurements. IOM recognized six areas of improvement which are needed in response to inconsistent care across a rapidly changing health system [28]. The six areas were designed to encompass core needs of quality care:

- Effective: providing evidence-based care to all who could benefit and refraining from providing services to those not likely to benefit;
- Efficient: avoiding waste, including equipment, supplies, ideas, or energy;
- Safe: avoiding injury,
- Patient-centered: respectful and responsive to patient preferences, needs, and values;
- Timely: reducing waiting and delays for those that give and receive care; and
- Equitable: care which does not vary according to gender, ethnicity, geographic location, or socioeconomic status [28].

The IOM included recommendations for a system redesign to include the development of measures for assessing quality of care [28].

On the other hand, Dr. Avedis Donabedian believed that quality assessment should include three critical elements in healthcare delivery: structure, process, and outcome [29].

- Structure measure: material resources; facilities, equipment, human resources (number of personnel and their qualifications), and organizational structures (funding and reimbursement)
- Process measure: how healthcare is given and received as guided by policy, standards, and procedures
- Outcome measure: the effect of care and its impact on the health status of patients and populations

The structure of quality healthcare delivery needs to be built upon the material resources such as facilities, equipment, human resources (e.g., number of personnel and their qualifications), and organizational structures (e.g., funding and reimbursement). In turn, good structure increases the likelihood of good process, which includes how healthcare is provided and received through policy, standards, and procedures. The consequence of good structure and good process increases the likelihood of good outcome, effect of care, and health status of patients and populations [30].

Knowledge of the linkage between the three elements needs to be known before quality assessment can be conducted [30]. Donabedian includes caution around the certainty of assessing quality as it is often bound by the current strengths and limitations of clinical science, and outcomes are influenced by multiple factors, including the antecedent process of care [30].

As our combination of IOM and Donabedian quality framework has developed, other perspectives have emerged which further interpret these foundational criteria. These include further description of performance metric functions. Firstly, the US Government Performance Results Act 1993 (Section 2801) [31] outlines strategic performance metrics in four main categories: outcome, output, impact, and input.

- Outcome measure: "An assessment of the results of a program compared to its intended purpose"
- Output measure: "A tabulation, calculation, or recording of an activity or effort that can be expressed in a quantitative or qualitative manner"
- Impact measure: "A measure of the direct or indirect effect or consequence resulting from achieving program goals"
- Input measure: "A measure of the resources used to achieve an outcome (e.g., employees and funding)"

Secondly, the Agency for Healthcare Research and Quality (AHRQ) states clear differences between a process measure and a patient outcome measure [32, 33].

- Process measure: a healthcare-related activity performed for, on behalf of, or by a patient (e.g., readmission rates or discharge status) [33].
- Patient outcome measure: "a health state of a patient resulting from healthcare" (e.g., physiologic measures, radiology and lab results, and morbidity) [32]

For example, hospital staff shortage may delay a patient discharge, or inadequate patient teaching may lead to a readmission which may not pertain to patient physiology, but potentially, the process of the hospital or health system [34].

Finally, there is a pragmatic consideration in the identification and development of performance criteria. They must be measureable, meaningful, and manageable [35].

- Indicators should be able to be measured either through qualitative or quantitative means.
- Indicators should be meaningful in that they reflect quality of care and are considered important by both the clients and providers of health services and that they reflect the quality of services provided.
- Finally, indicators need to be manageable. Service providers need to be able to influence them and improve them. They also need to be efficient: data collection as a byproduct of the services provided and is not costly to collect.

These conceptual understandings help to create a combined framework which identify and evaluate the range and nature of air ambulance outcome measures of quality care.

Objectives

The aim of this review will be to identify and evaluate the range and nature of air ambulance outcome measures reported in the literature and to construct a quality dashboard based on a sound conceptual framework.

The review will aim to address specific research questions:

1. What range of outcome measures are used in air ambulance literature?
2. What measurement instruments or tools were used to identify air ambulance quality of care?
3. Which air ambulance performance outcomes are utilized in our refined quality framework?
4. Can our quality framework create a performance dashboard for strategic improvement?

The PICO question is (P) patients critically ill or injured, (I) which require flight in a dedicated air ambulance, (C) we will not use comparison, and (O) air ambulance service outcome measures, constructed in a combined Institutes of Medicine and Donabedian quality dashboard.

Methods

The review protocol has been registered within the International Prospective Register of Systematic Reviews (PROSPERO) ID no. CRD42019144652 and is being reported in accordance with the reporting guidance Preferred Reporting Items for Systematic Review and Meta-Analyses Protocol (PRIMSA-P) statement [36] (see checklist in Additional file 1).

Studies will be selected according to the following criteria: study design, setting, population, intervention, and outcomes

Eligibility criteria

Study design

The review will include observational cohort, cross-sectional, longitudinal, interrupted time series, and systematic review studies. Randomized controlled, clinical controlled, and controlled before-after trials have numerous ethical constraints for air ambulance life and limb-saving interventions and cannot be balanced with a control group [37]. Therefore, these study designs will not be included in the search strategy.

Setting

The setting includes geographic (e.g., rural, urban, regional), multi-cultural, all levels of socioeconomic, and national/country of origin contexts.

The selected population (P) will include studies involving children, adolescents, and adults who are critically ill or injured (regardless of age or sex). The service intervention (I) we are considering are the following: patients which require flight on dedicated air ambulance missions/tasks (primary/scene/delayed primary/interfacility/interhospital/back-transfer), all aircraft type (helicopter/rotor-wing or fixed-wing), and crew mix (paramedic, nurse, doctor). The outcome (O) is first, to identify the range of air ambulance service outcome measures and their metric instruments represented in the literature, and second, to create a quality dashboard using a combined IOM and Donabedian framework, relevant to patients, providers, and policy-makers for future service improvement and planning.

Studies will be limited to articles published in English (from January 2001 onwards). These dates were chosen to coincide with the International Civil Aviation Organization (ICAO) recognition of new approaches to civil aviation safety risk and quality concerns in 2001

[38]. Exclusion criteria will include military studies, individual case studies, small case control studies outside of the general representative population (e.g., skier or snowboarder survival, SCUBA-related illness), equipment or device trials (e.g., active cooling apparatus for neonates, supraglottic airway devices), and drug or laboratory trials (e.g., diagnostic accuracy of serum lactate or mannitol dosing), as these are not relevant to the review.

Data sources and search strategy

The PubMed search strategy will use relevant Medical Subject Headings (MeSH) terms (Additional file 2). For example, (1) Air ambulance "Fixed-wing aircraft or helicopters equipped for air transport of patients." Subheadings may include classification, economics, ethics, history, legislation and jurisprudence, organization and administration, standards, statistics and numerical data, supply and distribution, and trends. No filters will restrict the MeSH major topics-only PubMed search builder options. (2) Outcome and Process Assessment (Health Care): "Evaluation procedures that focus on both the outcome and status (outcomes assessment) of the patient at the end of an episode of care—presence of symptoms, level of activity, and mortality; and the process (assessment, process)—what is done for the patient diagnostically and therapeutically." Subheadings may include classification, economics, epidemiology, ethics, history, legislation and jurisprudence, methods, mortality, organization and administration, psychology, standards, statistics and numerical data, and trends. No filters will restrict the MeSH major topics-only PubMed search builder options. Search will include topics found below the MeSH hierarchy tree, if available.

The initial search strategy will include four databases commonly used in medical searches: PubMed, MEDLINE Ovid, CINAHL, Scopus, and Cochrane Database of Systematic Reviews from January 2001 onwards. A complementary search will include three relevant journals: *Air Medical Journal*, *Emergency Medicine Australasia*, and *Annals of Emergency Medicine*, as each has a dedicated section in pre-hospital retrieval and emergency medicine transport from January 2001 onwards. If necessary, we will contact authors to identify additional sources. A draft search for PubMed is included in Additional file 2.

Study selection and data extraction

The selection process will use a pre-designed screening tool listing inclusion and exclusion criteria, and two authors (KHE, MTE) will independently examine study titles and abstracts following the PRISMA process. Screening will be managed in an Excel spreadsheet in descending chronological order of publication year and include complete citation. The authors will screen all citation titles and abstracts according to the selection criteria following the PRISMA process. The authors will record results with a colored Excel cell code and label extraction process. The cell color green means "yes," red color cell "no," or yellow color cell "maybe." The authors will obtain full-text articles for potential relevance and then examine for eligibility. The authors will then assess and discuss the result for agreement. A third author will be included in the event of unresolved discrepancies. The authors will attempt to contact study authors in this event, to resolve uncertainties. Two authors will independently extract study data using a piloted form (Additional file 3) and checked for accuracy by a third author. Data extracted will include sample size, country(ies) study was performed, study setting, patient age range, pathology type or characteristic, air craft type, mission type, mission time interval, data source and type, crew type, intervention metrics, exclusion and inclusion criteria, limitations, comparison measures, primary and secondary (if available) outcome measures, funding source, and study results. Data extractors will not be blinded to study citations. There are no preplanned assumptions or simplifications. Data extraction process steps will be maintained and managed using Microsoft Excel 2016. All publications will be managed using EndNote X8.

Review of selected articles

Complete review of selected articles will be read and organized using a table format (Additional file 3).

Outcomes and variations

The air ambulance outcome measures will further be defined according to the US Government Performance Results Act 1993 (Section 2801) [31]: "An assessment of the results of a program compared to its intended purpose." Outcome measures could incorporate any assessment of this target (e.g., mortality and morbidity rates, adverse events, time-to-patient intervals, referral patterns or crew qualifications, dispatch criteria, or base proximity to tertiary facilities). The authors will attempt to interpret regional or national variations in terminology, if necessary (e.g., interhospital or delayed primary mission), and report the variations in glossary format, in the "Results" section of the review.

Appraisal of evidence—risk of bias

Risk of bias quality will be assessed using ROBIS (risk of bias in systematic reviews) [39] and the Newcastle-Ottawa Scale (NOS) [40]. The ROBIS tool was chosen for the rigor in assessing the metabias in the systematic review process and the signaling questions as they relate to healthcare effectiveness (interventions) [40]. The NOS instrument was chosen for rigor in assessing the quality of nonrandomized studies. Three authors will independently assess the articles, one piloting and two with previous risk of bias appraisal experience. Disagreement between reviewers will be discussed until consensus is reached. Findings of the review will be included in the "Results" section and impact of bias, if any, in the "Discussion" and "Conclusion" sections. The ROBIS phase 2 applies signaling questions in four domains of key review processes at the study level: study eligibility criteria, identification and selection of studies, data collection and study appraisal, and synthesis and findings. ROBIS signaling questions are designed to "help assess specific concerns about potential biases" [39]. Each study level item will be assessed sequentially, not as "standalone units" [39]. ROBIS phase 3 process is at the outcome level, as a whole. This phase includes signaling questions and information to support the overall judgment of risk of bias. ROBIS assessment tools, for example ratings, signaling question explanations, and concerns for rating, will be used for guidance [39]. Answers to signaling questions are "yes," "probably yes" (low concerns), "probably no," "no" (higher concern), and "no information" (unclear). The table legend will include visual color and symbols for translation (Additional file 4). The NOS instrument assesses quality of selection (case definition, representativeness, case selection, control selection, control definition), comparability (case design or analysis), and outcome (assessment of outcome, length and adequacy of follow-up). Studies could be awarded a maximum score of 9 points. Studies with scores of 5 points or more are considered to be of moderate to good study quality [40]. NOS assessments will be presented in table format. Attempts will be made to contact authors for more information, if necessary. Appraisals will be made by three review authors based on ROBIS and NOS assessment guidelines. Disagreements will be resolved by discussion. If necessary, a fourth author will be consulted until consensus is reached.

Planned approach to synthesis and analysis

Authors will summarize search results in a PRISMA study flow diagram [41] and by narrative synthesis in text and table format. Description of the five-phase narrative synthesis process will improve protocol transparency and reproducibility [42]. The authors will first summarize selected study variables in table format. Second, the authors will explore the findings and relationships in the combined IOM and Donabedian framework (e.g., how "time-to-patient" relate within the quality domains) (Table 1), using cognitive reconstruction [44] by collecting the outcome measures, then working backward to connect effect links in the framework. Third, the authors will discuss effect differences within the frameworks in a narrative format. Fourth, the authors will undertake thematic content analysis of selected article findings and relationships within the framework, using cognitive reconstruction [44], in a table format. Finally, the authors will present a visual dashboard diagram for patients, providers, and policy-makers to consider for future service improvement and planning.

Table 1 Proposed dashboard distribution strategy of air ambulance outcome measure examples in a combined IOM and Donabedian domains

IOM domain of quality	Donabedian measure type	Donabedian measure type	Donabedian measure type
	Structural examples	Process examples	Outcome examples
Effectiveness examples:	Appropriate HR(qualifications, quantity), facilities (proximity population, tertiary), equipment (ECMO), or funding structures which incorporate EBM	Appropriate guidelines or policy driven by EBM	Improved patient survival
Efficiency examples	Appropriate HR, facilities, equipment, or funding which minimize waste of equipment, ideas, or energy	Guidelines and policy which appropriate tasking to avoid over/under triage	Decrease in patient mortality and morbidity
Safety examples:	HR, equipment, facilities, funding structures which meet aviation and clinical safety regulation	Aviation and health procedures and guidelines which facilitate swift and safe departures	Patient survival; avoiding adverse events
Patient-centeredness examples	HR quantity and qualifications to meet patient and population-specific needs	Current standards of care to meet patient-specific needs	Survival; respecting patient values and preferences
Timeliness examples	Equipment, facilities, funding structure, HR quantity, and qualifications for timely assessment and treatment implementation	Active governance which monitor total system response time	Improved patient survival due to timely care
Equity examples	Equipment, facilities, HR, and funding structure to meet time/distance/patient variation	Appropriate policy, standards and/or procedures to meet needs of remote and disadvantaged communities	Patient survival across gender, ethnicity, geographic location, or socioeconomic status variations

HR human resources, *EBM* evidence-based medicine [43]

Subgroup and sensitivity analysis
A subgroup or sensitivity analysis will not be undertaken in this review. The aim of the review is to identify and evaluate the range of air ambulance outcome measures reported in the literature, not to test the change effect of parameters.

Publication bias
Publication bias will not be explored in this review, as the aim of the review is to identify the air ambulance outcome measures and tools, not the positive or negative results of outcomes.

Discussion
Performance quality is able to be measured on many levels within the air ambulance health service: the front-line health providers, individual patient outcomes, the support systems (e.g., dispatch and triage), organizational structures (e.g., asset capability and availability), governance, and legislation. We acknowledge that quality is a challenging construct to define and measure in highly heterogenous, complex and interconnected emergency medical systems [45–48]. However, the first step is to explore air ambulance outcome measures as not an end, but rather the means to improving quality healthcare delivery [49]. The intent of this review is not to impose quality metric implementation, but rather introduce a generally accepted set of indicators which help to guage system-wide benchmarking and trend analysis [50]. Identification of the range of quality measurements reduces duplication, inconsistencies, and performance "gaps." Evaluation of quality measure eliminates metric "cherry picking," which highlights stakeholder's self-interests [51]. Failure to identify meaningful outcome measures hinders the ability to recognize disparity and variations of care [50].

Limitations
We acknowledge potential limitations of the review. These may include study inconsistencies in data collection and recording methods of critical information in the pre-hospital setting, such as field vital signs or response time [52]. Studies that use trauma registry data sources may have significant variability of definitions, standard measures, and case inclusion [52], which may influence study outcome. The authors acknowledge their limitations in language fluency, which are limited to English. Finally, there is a possibility to inadvertently miss relevant studies outside of our search strategy. Protocol amendments will be documented and available for open review on the PROSPERO website: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42019144652.

Conclusion
In summary, dedicated air ambulance services provide a vital link for critically ill and injured patients to higher levels of care. The recent developments in modern emergency medicine create an opportunity for air ambulance providers and policy-makers to utilize a dashboard of quality performance measures. Our systematic review contains the first step toward the development of an air ambulance quality dashboard, designed to combine frameworks of the Institutes of Medicine and Dr. Avedis Donabedian and further refined using the Agency for Healthcare Research and Quality and the US Government Performance Results Act 1993, which aims to provide a basis for strategic health service planning.

Supplementary information
Supplementary information accompanies this paper at https://doi.org/10.1186/s13643-020-01316-7.

Additional file 1. PRISMA-P 2015 Checklist.
Additional file 2. Medical Subject Headings (MeSH) terms.
Additional file 3. Review of selected article format.
Additional file 4. Risk of bias in systematic review using ROBIS sample.

Abbreviations
AHRQ: The Agency for Healthcare Research and Quality; Donabedian: Dr. Avedis Donabedian; IOM: Institutes of Medicine; PROSPERO: International Prospective Register of Systematic Reviews; ROBIS: Risk of bias in systematic reviews

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Authors' contributions
The study protocol was conceived by KHE, with critical input from MTE, GF, and RCF. KHE registered the protocol with the PROSPERO database and wrote the first draft of the protocol. MTE, GR, and RCF provided input into the design and edited the draft protocol. All authors commented on the paper for important intellectual content. The authors read and approved the final paper. KHE accepts full responsibility for the finished paper and controlled the decision to publish.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Additional file 1. PRISMA-P Checklist

(Included in online publication). Inclusion of PRISMA-P was mandated by the journal for all submissions, to indicate completeness and transparency of the protocol reporting. This checklist has been adapted for use with protocol submissions to *Systematic Reviews* from table 3 in Moher d et, al: Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews* 2015 4:1

Section/topic	#	Checklist item	Information reported Yes	No	Line number(s)
ADMINISTRATIVE INFORMATION					
Title					
Identification	1a	Identify the report as a protocol of a systematic review	☒	☐	3
Update	1b	If the protocol is for an update of a previous systematic review, identify as such	☐	☐	NA
Registration	2	If registered, provide the name of the registry (e.g., PROSPERO) and registration number in the Abstract	☒	☐	77-78
Authors					
Contact	3a	Provide name, institutional affiliation of all protocol authors; provide physical mailing address of corresponding author	☒	☐	30-31
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review	☒	☐	371-376
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments	☒	☐	337-339
Support					
Sources	5a	Indicate sources of financial or other support for the review	☒	☐	362-368
Sponsor	5b	Provide name for the review funder and/or sponsor	☒	☐	362-368
Role of sponsor/funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol	☒	☐	435-367
INTRODUCTION					
Rationale	6	Describe the rationale for the review in the context of what is already known	☒	☐	67-152
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)	☒	☐	162-164

Section/topic	#	Checklist item	Information reported Yes	No	Line number(s)
METHODS					
Eligibility criteria	8	Specify the study characteristics (e.g., PICO, study design, setting, time frame) and report characteristics (e.g., years considered, language, publication status) to be used as criteria for eligibility for the review	☒	☐	173-195
Information sources	9	Describe all intended information sources (e.g., electronic databases, contact with study authors, trial registers, or other grey literature sources) with planned dates of coverage	☒	☐	214-219
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated	☒	☐	219-220
STUDY RECORDS					
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review	☒	☐	239-241
Selection process	11b	State the process that will be used for selecting studies (e.g., two independent reviewers) through each phase of the review (i.e., screening, eligibility, and inclusion in meta-analysis)	☒	☐	233-239
Data collection process	11c	Describe planned method of extracting data from reports (e.g., piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators	☒	☐	232-238
Data items	12	List and define all variables for which data will be sought (e.g., PICO items, funding sources), any pre-planned data assumptions and simplifications	☒	☐	234-238
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale	☒	☐	251-258
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis	☒	☐	261-286
DATA					

Section/topic	#	Checklist item	Information reported Yes	No	Line number(s)
Synthesis	15a	Describe criteria under which study data will be quantitatively synthesized	☒	☐	292-303
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data, and methods of combining data from studies, including any planned exploration of consistency (e.g., I^2, Kendall's tau)	☒	☐	292-303
	15c	Describe any proposed additional analyses (e.g., sensitivity or subgroup analyses, meta-regression)	☒	☐	310-312
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned	☒	☐	299-301
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (e.g., publication bias across studies, selective reporting within studies)	☒	☐	315-316
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (e.g., GRADE)	☒	☐	277-286

Additional file 2. Medical Subject Headings (MeSH) terms

(Included in online publication).

Exact terms and combinations were included to increase transparency and reproducibility.

Data sources and search strategy

My search strategy will use relevant vocabulary in text combinations, truncation (*) (e.g., air ambulance*, aeromedical*), with search builder restrictions (e.g., AND, OR, NOT); keyword combination, truncation (e.g., patient outcome*, health service outcome*), with search builder restrictions (e.g., AND, OR, NOT); and Medical Subject Headings (MeSH) decision trees structures and search words.

Additional file 3. Review of selected article format

(Included in online publication).

Review of selected article format

Study	N (Total #)	Setting	Population Intervention	Comparison	Outcome
Results			Conclusions		Quality Level
Metrics:			Excluded:		
Data linkage methods:					
Limitations:					
Data type:					
Data source:					
Mission type:					
Crew type:					
Funding source:					

Additional file 4. Risk of bias in systematic review using ROBIS sample

A sample was included to increase protocol process transparency.

Risk of bias in systematic review using ROBIS sample

Study	Phase 2				Phase 3	Author note
Author (year)	1. Study eligibility criteria	2. Identification and selection of studies	3. Data Collection and study appraisal	4. Synthesis and findings	Risk of bias in the review	Rationale
Jane Doe (2019)	+	-	-	?	+	Narrative description

Table key: + = low concern; - = high concern; ? = unclear risk.

3.9 Supplementary files relating to thesis methods

Appendix B. Tables 'Quantitative data sources'.

Appendix C. Tables 'Qualitative research participant information sheet'.

Appendix D. Tables 'Permissions'.

Appendix E. Figures 'Diagnosis chapters'.

3.10 Chapter summary

Chapter 3 is a summary of the methods used in the thesis and addresses aims 1-4. A sequential multiple methods approach was undertaken to explore these aims. Data linkage cleaning and preparation identifies novel time interval gaps and usage of 'timestamps' by service providers. The scoping review protocol provides detailed planning to document the range and nature of outcome measures in the literature and for the development of the aeromedical quality framework. Methods for each study are detailed in the relevant chapters.

3.11 Salient points

- Data collection occurred in three phases; 1.) Isolated aeromedical data, 2.) Linked aeromedical, hospital, ED, and death data, 3.) Clinician interviews.
- Data linkage, cleaning and preparation of the aeromedical sources identified overlaps or 'shared' information which were combined and formed each aeromedical episode.
- Description and definition of time stamp events are vital to understand the aeromedical patients' journeys.
- Three types of time gaps were identified along the aeromedical patients' journeys.

3.12 Chapter references

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Chapter 4. Results of aeromedical-only data: A program profile of air medical transport in regional Central Queensland

Overview of the chapter

Chapter 4 comprises the third publication of the thesis and the first of two phases exploring the patient and service results of aeromedical retrieval in Central Queensland. This is the first of two chapters addressing aim 3 of the thesis, to explore aeromedical patients' journeys in Central Queensland. This paper is designed as a pilot study, the first to explore air medical transport patterns in Central Queensland Health and Hospital Service (CQHHS). The aggregated results of this study identify three limitations: lack of mission type (e.g., IHT or back-transfer), lack of patient disposition data, and lack of the International Classification of Diseases (ICD) coding, which prompts the need for data linkage in chapter 5.

The results of this study identified referral pattern movements in CQHHS with the largest group of referrals received in the region. Cardiac-related illness were the largest reasons for referral transfers. Men aged 66 and older represented the most frequent aeromedical patient group. Finally, the most frequent aircraft type was fixed-wing and most frequent priority response category was 6-24 hours. Figure A. summarises the main aims and outputs from the thesis and indicates the position of this chapter within the thesis.

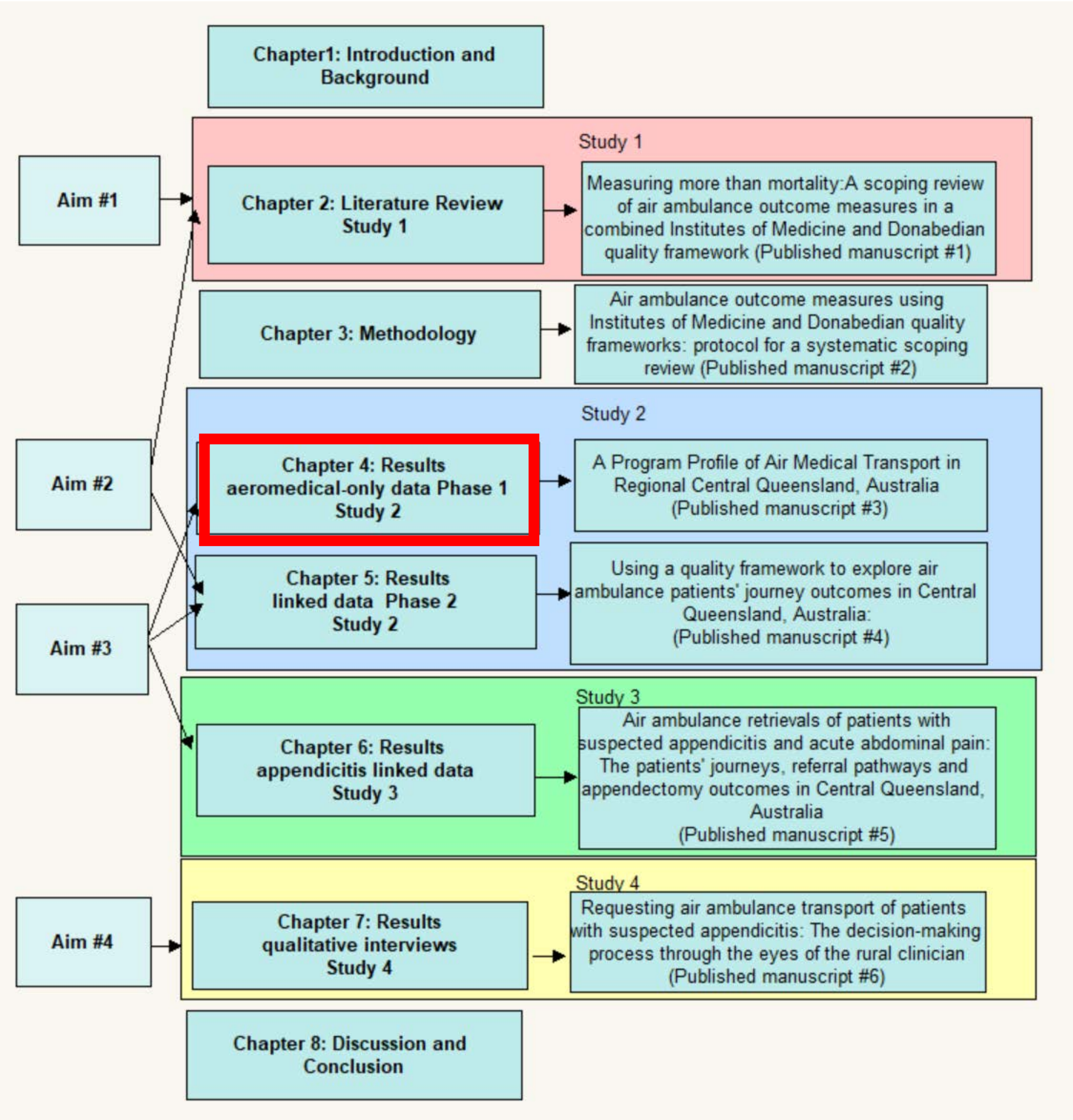

Figure A. Conceptual model of thesis aims and outputs

Study aims 1-4 are in boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a red box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

4.1 Manuscript

This chapter contains the following manuscript that has been published in a peer-reviewed journal, relevant to aeromedical retrieval, and is inserted as a published .pdf in the format required by Air Medical Journal:

This chapter comprises a published manuscript. It is inserted as published. The citation is:

Edwards, K.H., Franklin, R., Aiken, P., Elcock, M., Edwards, M.T. (2019). A program profile of air medical transport in regional Central Queensland. *Air Medical Journal*. https://doi.org/10.1016/j.amj.2019.09.003

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Original Research

A Program Profile of Air Medical Transport in Regional Central Queensland, Australia

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A B S T R A C T

Objective: The purpose of this study was to investigate the epidemiology of air medical patients and referral patterns in Central Queensland Hospital and Health Service (CQHHS).
Methods: Analysis of air medical transport from January 2010 to December 2014. Air medical tasks within the local health service boundary were included. All patients transported on rotor or fixed wing aircraft for medical purposes were included. Patterns of air medical tasks in and out of the region by referring and receiving location, aircraft type, flight priority, time of day, month, sex, age, illness, and referral indexes were analyzed.
Results: There were 11,456 air ambulance tasks in CQHHS region during the study period, an average of 2,291 retrievals per annum or 191 per month. Frequent referrals were to a tertiary facility, located 800 km across economic and political boundaries. Referral pattern indexes highlight a net patient flow of 1.2 to 1. Cardiology was the largest illness category (24%). Males represented 59% overall as well as patients 66 years and older (33%). Fixed wing aircraft carried out 87% of the tasks with a frequent response time of 6 to 24 hours.
Conclusion: Air medical transports are an integral part of the health system in Central Queensland communities with vast geographic distances. Identifying regional referral pattern rates and ratios aid in the planning of resource allocation.

In Queensland, Australia, centralized air medical coordination helps to address challenges around the management of complex health needs distributed across a vast geographic area.[1] Recent decentralization of health and hospital regions in Queensland created regional health systems that cross political and economic boundaries.[2] Referrals of ill and injured patients requiring specialized services across health service boundaries may be resource efficient, but the effectiveness of service delivery is not clear. Analysis of local usage, market share division, and net patient flow indexes may help to define regional referral patterns.[3]

Referral decisions are complex, often an interplay between medical and nonmedical characteristics such as previous experience, health provider recommendations, patient treatment preferences, and resource availability.[4,5] A better understanding of air medical referral and transport patterns may identify hospital capacity variations and health care system effectiveness. The aim of this study is to explore the epidemiology of patients and referral patterns of air medical services in Central Queensland, Australia.

Background

Queensland health regions were established in 2012 to decentralize care and improve the management of local health needs.[2] The Central Queensland Hospital and Health Service (CQHHS) district boundary covers a geographic area of 114,000 km^2 and had an

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estimated resident population of 226,273 in 2012,[6] with an average annual population growth of 2%.[7]

Rockhampton Public Hospital has a 246-bed capacity.[8] Services include a 24-hour emergency department; a general outpatient department; general medical and surgical, critical care, pediatric, obstetrics, radiology, rehabilitation, and palliative care wards. Rockhampton Public Hospital emergency department admissions were 77,212 in 2012 to 2013 and 126,000 patients in 2013 to 2014, an increase of 63% over the study period.[8] Seventeen small rural hospitals, clinics, and multipurpose health services are located within CQHHS and one main public hospital in Rockhampton and two smaller private hospitals. The towns include Baralaba, Biloela, Blackwater, Yeppoon, Emerald, Gladstone, Moura, Mount Morgan, Rockhampton, Springsure, Theodore, and Woorabinda.[8] The closest tertiary and quaternary facilities are located in the capital city of Brisbane (Fig. 1).

Methods

Statewide air medical retrieval data were collected by the Retrieval Services Queensland (RSQ), a division of Queensland Department of Health. Nonidentifiable information was extracted for this study. RSQ orchestrates statewide emergency agencies and providers to exchange asset availability, aviation, and clinical risk levels.[9] Study period dates of January 1, 2010, to December 31, 2014, were chosen because of the availability of data. A total of 11,456 CQHHS air medical tasks were recorded using fixed and rotor wing aircraft. The fixed wing service used two Beechcraft King Air. The rotor wing service used one Sikorsky S-76 (Capricorn Helicopter Rescue Pilot Mitch Vernon, personal communication, March 2017). The data did not differentiate the type of task (ie, interhospital transfer, scene, or back transfer) nor did it indicate the number of patients in the aircraft per flight. Therefore, all air medical patient transfers are referenced as “tasks.”

The selection of participant inclusion criteria included all air medical patients transported within the CQHHS boundary, coming into the boundary, and those leaving the health service boundary during the study period. The health and hospital region of Central Queensland is determined by Queensland Health. Local government area (LGA) postcodes were used to determine participation inclusion. The LGA regions of Central Queensland include Banana Shire Council, Central Highlands Regional Council, Gladstone Regional Council, Rockhampton Regional Council, Woorabinda Aboriginal Shire Council, and Livingstone Shire Council.[10] Road transport, commercial flights and Australian Search and Rescue cases were excluded.

Patient priority status is designated by RSQ to ensure that retrieval requests are triaged by need to allow for efficiency. These categories are arranged by the urgency of the case, which may differ from the severity of patient illness. Tasking the priority category may not correlate with patient trauma scoring and evaluation or mortality prediction. Generally, patient priority status determines aircraft and crew response time; ready for departure[9] (Table 1).

The patient illness and injury presentation were classified by RSQ. The data did not follow *International Statistical Classification of Diseases, 10th Revision* categories. Data were analyzed using SPSS Version 22 (IBM Corp, Armonk, NY).

Regional transfer pattern indexes show rates and ratios of air medical patient flow across health service districts. Localization, market share, and net patient flow indexes help to visualize patient movement patterns. Each of the 3 indexes were modified from Wallace et al[3] because the resident zip code was not available. First, the *modified localization index* is the percentage of air medical patient tasks treated in the Central Queensland region and originated in the Central Queensland region (equation 1). Indexes closest to 100% represent the patient treatment rate within the health boundary.

$$\frac{\textit{Treated in CQHHS}}{\textit{Originate in CQHHS}} \times 100 = \textit{Modified Localization Index}\% \qquad (1)$$

Second, the *market share index* is the percentage of air medical patient tasks treated in the Central Queensland region over the total

Figure 1. A Partial Map of Eastern Queensland Starring Regional Central Queensland.

Table 1
Patient Priority Status

Priority Status	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5
Aircraft and crew ready for departure:	FW: 30 minutes in day light 0800-2000, 45 minutes in night 2000-0800.	1-3 hours	3-6 hours	6-24 hours	>24 hours
		Both FW and RW aircraft day or night	Both FW and RW aircraft day or night	Both FW and RW aircraft day or night	Both FW and RW aircraft day or night
	RW: 15 minutes in day light 0800-2000, 30 minutes in night 2000-0800.				

Queensland Emergency Helicopter Network Tasking Guidelines (2011)[9] FW=Fixed Wing, RW=Rotor Wing.

share of air medical tasks (equation 2). Indexes closest to 100% represent the total market share within the health service boundary.

$$\frac{\textit{Treated in CQHHS}}{\textit{Total Task Share}} \times 100 = \textit{Modified Market Share Index \%} \quad (2)$$

Finally, the *net patient flow* is the ratio of air medical patient tasks originated in Central Queensland but are treated in another region over the air medical patient tasks originated in CQHHS but are treated in another region (equation 3). The index reflects the net movement of patients among referral regions.

$$\frac{\textit{Originated in CQHHS, treated in another region}}{\textit{Originated in CQHHS, treated in CQHHS}} \times 100 = \textit{Modified Net Patient Flow} \quad (3)$$

Results

There were 11,456 air ambulance tasks in the CQHHS region during the study period, an average of 2,291 retrievals per annum or 191 per month. There were 6,481 tasks received into Rockhampton Public Hospital, and 4,459 tasks referred out of Rockhampton Public Hospital in the study period. There was a small linear increase of 1%, equal to 28 cases per annum. Incomplete data included 516 tasks (4%) without referral region, missing data for illness and injury 53 tasks (<1%) and aircraft type for 441 tasks (4%)

Priority 4 was the largest category with 4,770 (42%) of all tasks. Over half of all flight tasks were males (59%). Patients aged 66 and older represented one third (33%, comprised 3,699 tasks) of all retrievals. Fixed wing aircraft carried out 9,931 tasks (87%). Busy peaks for tasks within a 24-hour period rise at 0800 and begin to slow at 1600. Monthly tasks rise during July (1,069 tasks, 9%) and August (1,054 tasks, 9%) (Table 2).

The ratio of males to females with an injury condition was 2:1, with the exception of those 40 to 65 years old, where the ratio between men and women increased to 3:1. Males with cardiology conditions across all ages represented 16% of the total tasks. Men in the 40 to 65-year age bracket had just over twice the number of cardiology flights compared with women the same age and with the same condition. However, the cardiology ratio increases in men aged 66 and older (ratio of 1.7:1) (Table 3).

Fixed wing aircraft carried out 9,931 tasks (86.7%), whereas rotor wing aircraft accounted for 1,084 tasks (9%). The largest illness category for rotor wing was 413 (38%) injury tasks, and for fixed wing, it was cardiology (2,570, 26%).

Table 2
Demographic Summary of Air Medical Tasks in the Central Queensland Health and Hospital Service Region

Variable	Air Medical Tasks
Air medical tasks (2010-2014)	11,456
Adult patient (18 years and older), n (%)	9,862 (86)
Pediatric patient, n, (%)	1,594 (14)
Male, n (%)	6,714 (59)
Female, n (%)	4,742 (41)
Fixed wing, n (%)	9,931 (87)[a]
Rotor wing, n (%)	1,084 (9)[a]
Priority status categories, descending mean, n (%)	1. Priority 4, 4,770 (42)
	2. Priority 3, 2,511 (22)
	3. Priority 1, 1,549 (14)
	4. Priority 2, 1,607 (14)
	5. Priority 5, 871 (8)
Busiest time of day, mode	0800-1600
Busiest month/season of year, mode, n (%) adjusted	July/Winter, 1,066 (9)
Furthest referral task from Rockhampton, air km	Mt. Isa, QLD 1,172 km
Furthest receiving task to Rockhampton, air km	Royal Adelaide Hospital, South Australia 1,730 km
Facility referral from Rockhampton, mode	Royal Brisbane & Women's Hospital (public, urban tertiary)
Facility receiving to Rockhampton, mode	Emerald Hospital, QLD (public, rural hospital)

[a] Incomplete aircraft type data (441 tasks, 4%).

Receiving Tasks (Coming Into) Rockhampton Public Hospital

Retrieval Services Queensland coordinated 11,456 tasks coming into and out of the CQHHS region (Fig. 1). Rockhampton Public Hospital received 6,481 tasks coming in from 68 different health facilities across Queensland, New South Wales, and South Australia. Of these receiving tasks, 6,008 (93%) were brought to Rockhampton Public Hospital; smaller private hospitals in Rockhampton received the remaining 7%. Rockhampton hospitals received 3,552 tasks (55%) from within the CQHHS boundary from rural hospitals, clinics, and multipurpose health centers. The most common receiving tasks to Rockhampton, from within the CQHHS boundary, came from rural Emerald Hospital (1,297, 20%), which is 270 km west of Rockhampton. For receiving tasks into Rockhampton from outside of the CQHHS boundary, 45% (2,929) come from tertiary and quaternary hospitals in the capital city of Brisbane (Fig. 2). Brisbane private hospitals sent 27 tasks (<1%), and pediatric flights accounted for 15 tasks (<1%) to Rockhampton. The furthest flight coming into Rockhampton Public Hospital was from the Royal Adelaide Hospital in South Australia, approximately a 1,730-km flight path. These receiving tasks from capital cities were likely step-downs, required lower levels of care, closer to patients' communities.

Referring Tasks (Leaving) Rockhampton Public Hospital

Rockhampton Public Hospital referred out 4,459 tasks (Fig. 3). Most tasks from Rockhampton Public hospital, comprising 4,296 (97%), were sent outside of the CQHHS boundary. The furthest flight was to Mount Isa, 1,172 km to the northwest. The greatest number of

Table 3
Condition, Sex, Age, and Flight Priority Status Flight Occurrences

Top 7 Conditions, (n, %)	Male (n)	Female (n)	Age 0-4 Years(n)	Age 5-18 Years(n)	Age 19-65 Years(n)	Age 66 Years and Older(n)	Priority 1(n)	Priority 2(n)	Priority 3(n)	Priority 4(n)
Cardiology (2,688, 24%)	1,756	923	31	10	1,293	1,345	376	340	469	1,234
Medical (1,930, 17%)	1,026	748	414	97	714	556	180	168	235	572
Surgical (1,564, 13%)	951	704	21	131	1,007	496	212	185	314	723
Injury (1,175, 10%)	765	348	80	262	701	70	146	112	191	393
Musculoskeletal (1,082, 9%)	652	413	11	108	587	359	10	13	23	34
Neurologic (763, 7%)	470	289	49	58	410	243	104	92	129	295
Respiratory (550, 5%)	322	227	231	37	173	109	29	34	54	132

tasks referred from CQHHS was to the Royal Brisbane and Women's Hospital with a total of 1,951 flights (44%). The Prince Charles Hospital received 855 flights (20%), and The Princess Alexandra Hospital received 161 flights (4%). Overall, these three tertiary facilities in the capital city of Brisbane received 2,967 (68%) from CQHHS. Brisbane's private hospitals received 310 tasks (7%). The Brisbane Children's Hospital received 270 tasks (6%). Only one tertiary hospital, Townsville, is located outside of Brisbane (850 km north of Rockhampton), which referred 20 tasks (<1%) (Fig. 3).

Regional Transfer Patterns

Transfer pattern indexes show rates and ratios of patient flow across health service districts. In CQHHS, transfers to tertiary facilities cross boundaries of economic, political, and vast geographic distances. Localization, market share, and net patient flow indexes visualize patient movement patterns (Figs. 4–6).

Discussion

Air medical transfer patterns reflect regional health system effectiveness and efficiency.[3] Patterns that move the patient out of health service districts may reflect local hospital capability levels.[3] Increasing trends of patient movement act like the canary in the coal mine, where movement patterns out of health service boundary may indicate gaps in local service provision and/or delivery. Patient transport, which requires significant time over great distances using limited aircraft with no guarantee of availability, may not deliver equitable quality care to rural communities. Analyses into the air medical transfer patterns are better understood with localization,

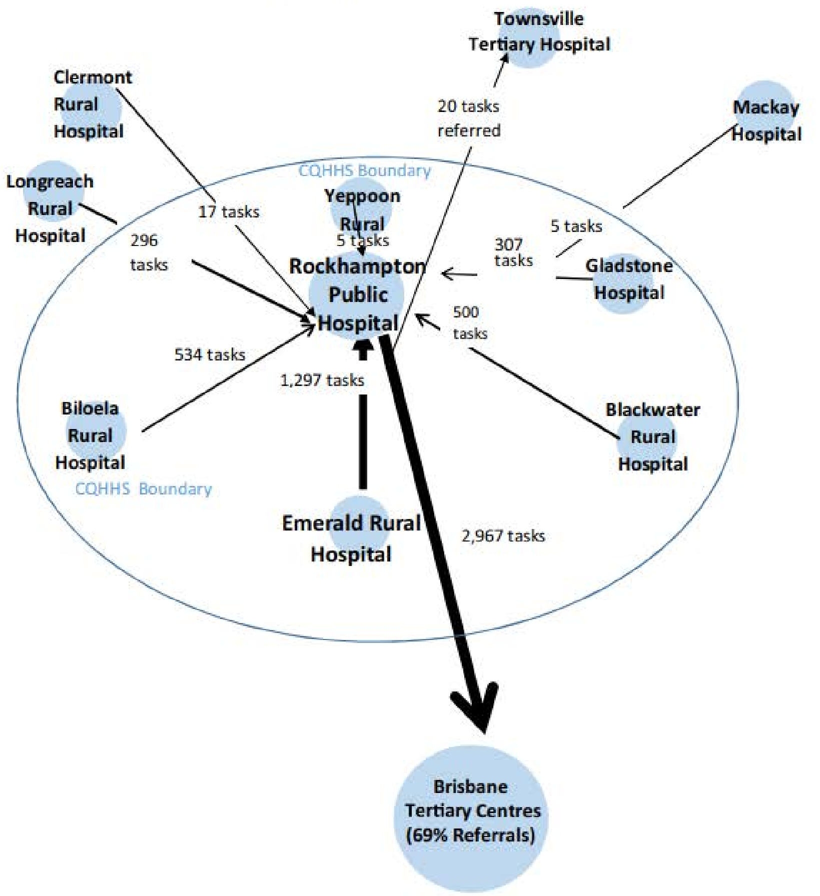
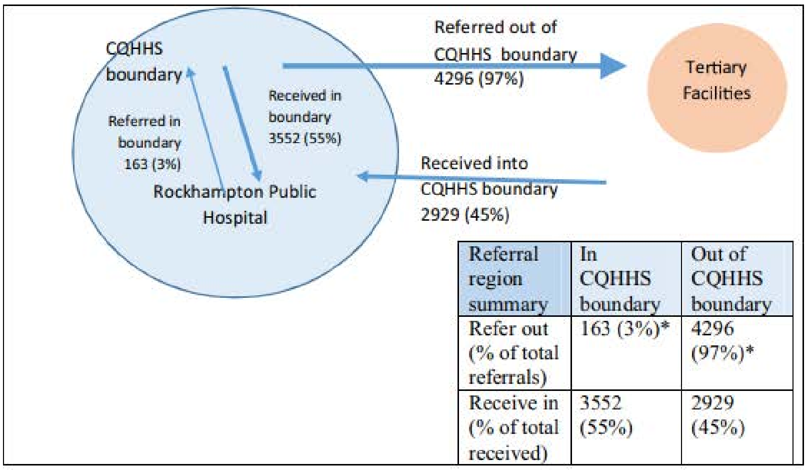
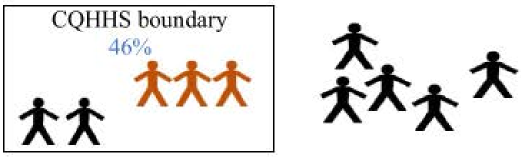


Figure 2. CQHHS Air Medical Regional Transfer Pattern Sample.



Referral region summary	In CQHHS boundary	Out of CQHHS boundary
Refer out (% of total referrals)	163 (3%)*	4296 (97%)*
Receive in (% of total received)	3552 (55%)	2929 (45%)

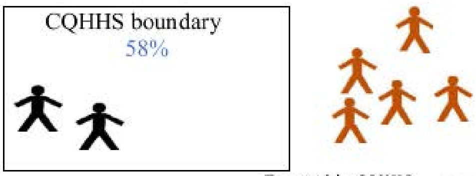
Figure 3. The tasks into and out from the CQHHS region. The total referred was 4,459, the total received was 6,481, and the total sum was 11,456. *Five hundred sixteen tasks without the referral region indicated.



$$\frac{Treated\ in\ CQHHS}{Originate\ in\ CQHHS} \times 100 = Modified\ Localization\ Index\%$$

$$\frac{3552 + 163 = 3715}{3552 + 163 + 4296 = 8011} \times 100 = 46\%$$

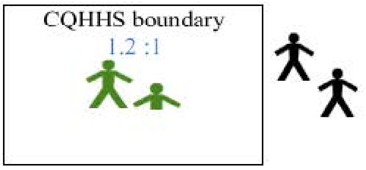
Figure 4. The modified localization index is the percentage of air medical patients treated in the Central Queensland region (red icons = 3552 patients received within the CQHHS boundary + 163 patients referred within CQHHS boundary = Total 3715 patients treated in CQHHS region) over air medical patients who originate in the Central Queensland region (black icons = 3552 CQHHS originated patients received in boundary + 163 CQHHS originated patients referred in boundary + 4296 CQHHS originated patients, but flown out of boundary = Total 7,848 patients originate in CQHHS). Tasks originating from a tertiary hospital and arriving to a facility with lower-level capabilities were assumed to be step-down or return flights to patient communities. All icons (Figs. 4-6) roughly illustrate patient movement in and out of CQHHS boundary and are not intended for exact representation.



$$\frac{Treated\ in\ CQHHS}{Total\ Task\ Share} \times 100 = Modified\ Market\ Share\ Index\%$$

$$\frac{3552 + 163 + 2929 = 6644}{11456} \times 100 = 58\%$$

Figure 5. The market share index is the percentage of patients who are treated in the Central Queensland region (black icons= 3552 patients received in CQHHS boundary and treated in CQHHS boundary + 163 patients referred in CQHHS boundary and treated in CQHHS boundary + 2929 received into CQHHS boundary for treatment from out of CQHHS boundary= Total 6,644 patients treated in CQHHS) over the total tshare of all air medical tasks (red icons = 11,456 patient transfers).



$$\frac{Originated\ in\ CQHHS, treated\ in\ another\ region}{Originated\ in\ CQHHS, treated\ in\ CQHHS} \times 100 = Modified\ Net\ Patient\ Flow$$

$$\frac{4296}{3552 + 163 = 3715} \times 100 = 1.2 : 1\ ratio$$

Figure 6. The net patient flow is the ratio of patients who originate in CQHHS but are treated in another region (black icons = 4296 patients) over the patients who originate in CQHHS and are treated in CQHHS (green icons = 3552 patients orginate in CQHHS, received in CQHHS + 163 patients orginate in CQHHS and referred in CQHHS, all treated in CQHHS, Total =3715 patients). The index reflects the net movement of patients among referral regions.

market share, and net flow indexes. Further understanding of flight frequency and patient characteristics of established health service districts may indicate to policy makers if service delivery is hitting their intended mark.

Prior studies comparing direct transport with a tertiary center and interhospital transfer (IHT) patient outcomes have mixed outcome results and often isolate trauma in metro and urban scenarios.[11] One particular study[12] compared the transport of a ground ambulance versus a helicopter for neurosurgical trauma. Due to the great vastness in our Central Queensland study (8+ hours by ground), these findings have little homologous value. Timeliness and efficiency will impact patient outcome. Significant consideration in transport tasking may also involve the "second hit" of trauma—multiorgan failure and sepsis as a result of the systemic inflammatory response to significant injury.[13] A better understanding of patient transfer outcomes and resource utilization is necessary for quality patient care.

Cardiovascular disease carries the greatest burden of disease in Australia.[14] The results in our study show the most common tasks were cardiac related. This may reflect disparities in cardiovascular health for rural communities. Improved future accessibility to acute cardiac service, recovery, and rehabilitation may include bringing medical teams directly to rural clinics. Understanding the patterns of these condition-specific transfers will help plan community needs and improve service efficiencies.

Strengths and Limitations

This is the first study to explore air medical transport patterns in CQHHS. However, the data did not indicate if tasks were single-step flights, multiple-step flights, back transfers, primary transfers (also referred as scene or trauma tasks), or secondary (interhospital or interfacility) transfers. Future research using a linked data approach will help to better understand the multistep patient journey and the primary and secondary missions. Further linkage of air medical data to emergency department, hospital, and discharge databases will provide information on patient outcomes and allow for a more comprehensive service delivery assessment.

Coding of illness groups did not use the *International Classification of Diseases* at the time of data collection. Patients may have been classified in multiple illness categories, therefore making it difficult to study the illness distribution and concentration for the district. Future research into this area is needed to identify reasons for condition-specific transfers.

Conclusion

This is the first retrospective, descriptive analysis to explore the air medical transport patterns in CQHHS within an Australian context; a large landmass with sparse rural and remote population. There was a small increase in the number of tasks carried out over the study period. The majority of transfer patients were men over 66 years of age with cardiac-related illness flown on fixed wing aircraft. The most common designated departure time was 6 to 24 hours with 69% of referrals sent to tertiary centers 800 km outside of the health and hospital district. These preliminary results require further exploration into condition-specific patient outcomes and the timeliness of service delivery.

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4.2 Chapter summary

This study is the first retrospective descriptive analysis to explore aeromedical patient and service outcomes in the Central Queensland Hospital and Health Service region. Patient outcomes include: sex, age, and broad category (non-ICD codes) reason for transport. Service outcome variables include: priority response categories, year of flight, time of day and month, aircraft type, and transfer patterns (modified net patient flow, modified market share index, and modified localisation index). The limitations of the study are used to build a more comprehensive analysis of the patient and service outcomes in phase 2. This next phase explores the linked data analysis of aeromedical, ED, hospital, and death registry.

4.3 Salient points

- This study was the first to explore aeromedical patient and service outcomes in CQHHS.
- Health regions in Queensland are decentralised to improve management of unique community needs.
- CQHHS covers a vast geographic area of 114,000 km^2.
- Overall, there were 11,456 records identified in the study.
- Priority category 4 was the most frequent category (4,770 records, 42% of the overall study total) with a response time of 6-24 hours.
- Men represented 59% of the overall study.
- Older patients (aged 66 and older) were most frequently represented (3,699 records, 33% of the overall total).
- Males with cardiovascular-related illnesses, across all age groups, represented 16% of the total records.
- The modified market share index indicated that aeromedical retrievals referred out of the CQHHS region represented 58% of the overall total.

Chapter 5. Results for linked data: Using a Quality Framework to Explore Air Ambulance Patients' Journey Outcomes in Central Queensland, Australia

Overview of the chapter

Chapter 5 is the second phase of a two-phase study exploring patient and service outcomes of data from aeromedical, ED, hospital, and death registry sources. This is the second study addressing thesis aim 2 and aim 3 and is the first of three publications.

- aim 2: To use the results of aim 1 to develop an aeromedical quality framework and use it for reporting existing aeromedical patient and service outcomes,
- aim 3: To explore the aeromedical patients' journeys in Central Queensland using linked data.

This study builds upon the limitations of chapter 4, to utilise patient data and service outcomes which are inherently linked and as a primary objective to explore how they can be used in an aeromedical quality framework.

At the commencement of the study, aeromedical data had not been linked to ED, hospital, and death registry data. Therefore, this study contributes a novel methodology to examine aeromedical patients' journeys. Further, the linked data can be compared to the aeromedical-only analysis in chapter 4 because of the shared study region and time period. The comparison of outcome measures between the aeromedical-only analysis and the available linked data outcome measures are provided in Table 5.5 (Section 5.2 additional analysis). Figure A summarises the main aims and outputs from the thesis and indicates the position of this chapter within the thesis.

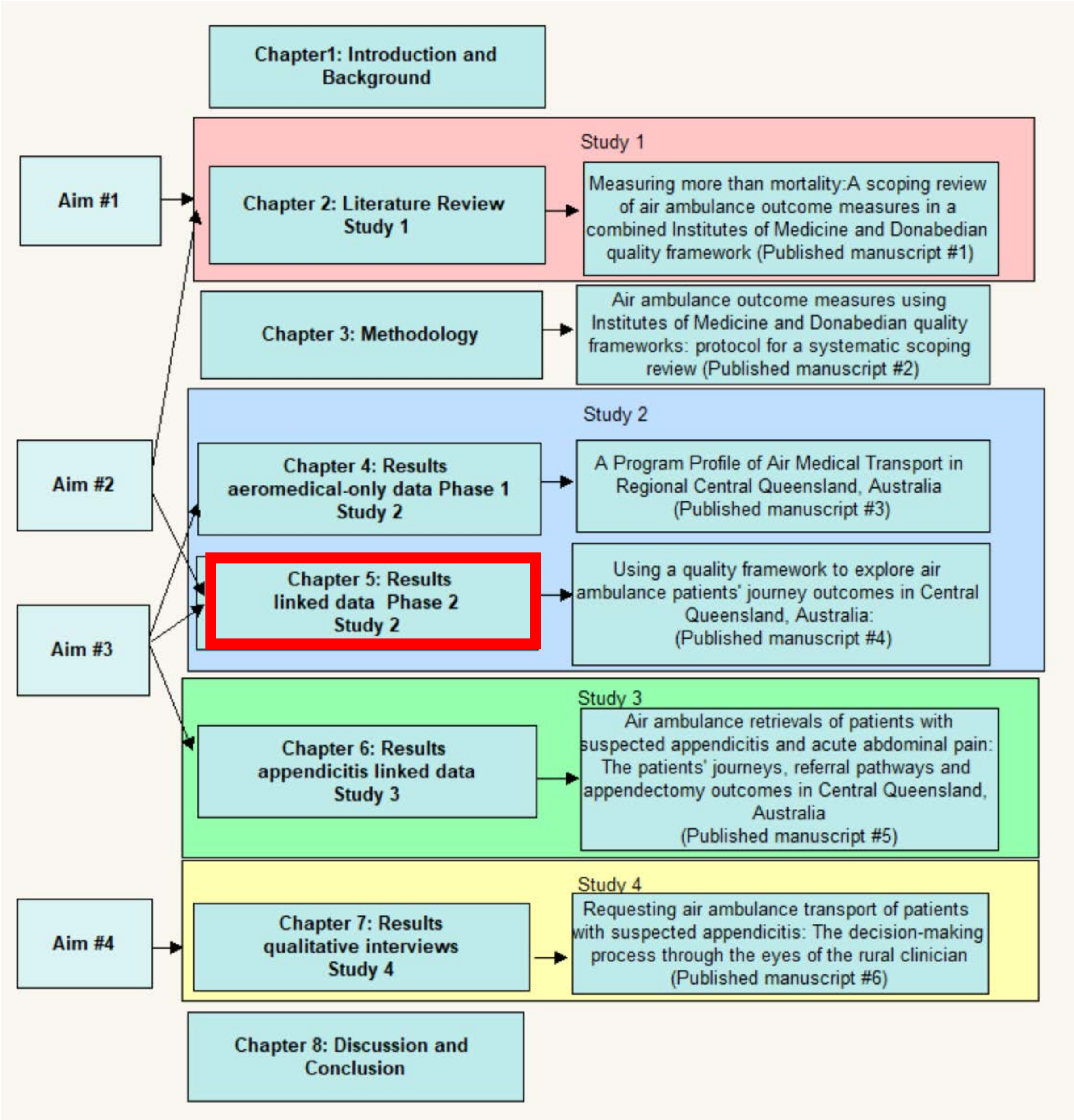

Figure A. Conceptual model of the thesis aims and outputs

Study aims 1-4 are in the boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a red box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

5.1 Manuscript

This chapter contains the following manuscript that has been published in a peer-reviewed journal, relevant to aeromedical retrieval, and is inserted as a published .pdf in the format required by Prehospital and Disaster Medicine:

This chapter comprises a published manuscript. It is inserted as published. The citation is:

Edwards, K.H., Franklin, R., Kuhnert, P., Jones, R., Khanna, S. (2022). Using a Quality Framework to Explore Air Ambulance Patients' Journey Outcomes in Central Queensland, Australia. *Prehospital and Disaster Medicine,* 1-8. doi:10.1017/S1049023X22001480

ORIGINAL RESEARCH

Using a Quality Framework to Explore Air Ambulance Patients' Journey Outcomes in Central Queensland, Australia

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Keywords: air ambulance; health care quality; mortality; patient outcome assessment; prehospital emergency care

Abstract

Introduction: In Australia, aeromedical retrieval provides a vital link for rural communities with limited health services to definitive care in urban centers. Yet, there are few studies of aeromedical patient experiences and outcomes, or clear measures of the service quality provided to these patients.

Study Objective: This study explores whether a previously developed quality framework could usefully be applied to existing air ambulance patient journeys (ie, the sequences of care that span multiple settings; prehospital and hospital-based pre-flight, flight transport, after-flight hospital in-patient, and disposition). The study aimed to use linked data from aeromedical, emergency department (ED), and hospital sources, and from death registries, to document and analyze patient journeys.

Methods: A previously developed air ambulance quality framework was used to place patient, prehospital, and in-hospital service outcomes in relevant quality domains identified from the Institutes of Medicine (IOM) and Dr. Donabedian models. To understand the aeromedical patients' journeys, data from all relevant data sources were linked by unique patient identifiers and the outcomes of the resulting analyses were applied to the air ambulance quality framework.

Results: Overall, air ambulance referral pathways could be classified into three categories: Intraregional (those retrievals which stayed within the region), Out of Region, and Into Region. Patient journeys and service outcomes varied markedly between referral pathways. Prehospital and in-hospital service variables and patient outcomes showed that the framework could be used to explore air ambulance service quality.

Conclusion: The air ambulance quality framework can usefully be applied to air ambulance patient experiences and outcomes using linked data analysis. The framework can help guide prehospital and in-hospital performance reporting. With variations between regional referral pathways, this knowledge will aid with planning within the local service. The study successfully linked data from aeromedical, ED, in-hospital, and death sources and explored the aeromedical patients' journeys.

Edwards KH, Franklin RC, Jones R, Kuhnert PM, Khanna S. Using a quality framework to explore air ambulance patients' journey outcomes in Central Queensland, Australia. *Prehosp Disaster Med.* 2023;38(1):57–64.

Abbreviations:
ANOVA: Analysis of Variance
ARIA+: Accessibility/Remoteness Index of Australia
CQHHS: Central Queensland Hospital and Health Service
ED: emergency department
ICD-10-AM: International Classification of Diseases, Australian Modification, 10th Revision
ID: identification
IOM: Institutes of Medicine
LOS: length-of stay
SSB: Statistical Service Branch

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Supplementary files provided with publication 4

Supplementary S1. Mortality summary among referral pathway subgroups

Variable	Referral pathway subgroups Intraregional 3536	OUT of region 7776	INTO region 2665	Study total 13977
Death after flight				
Total n(% of total)	304(9)	949(12)	675(25)	1928(14)***
Time post-flight to death 0-7 days n(%)	55(18)	118(12)	60(9)	233(12)***
7-31 days n(%)	32(11)	104(11)	115(17)	251(13)
1-6months n(%)	46(15)	176(19)	182(27)	404(21)
6-12month n(%)	23(8)	102(11)	65(10)	190(10)
>1 year n(%)	145(48)	443(47)	250(37)	838(44)
Death All Cause top three				
Cancer n(%)	74(24)	332(35)	319(47)	725(38)
Circulatory n(%)	75(25)	263(28)	138(20)	476(25)
Respiratory n(%)	33(11)	61(6)	53(8)	147(8)
*Death **0-7days** after flight*				
Most frequent category of death 0-7days after flight				
Cardiology n(%)	18(33)	51(43)	11(18)	80(34)
flight priority(P1-P5)(%)	P1(38)	P4[a](39)	P4(45)	P4[a](34)
sending ARIA+ (%)	Rural(63)	Inner Regional(51)	Rural(73)	Inner Regional(36)
Second most frequent category of death 0-7days after flight				
Cancer n(%)	8(15)	23(19)	34(57)	65(28)
flight priority(P1-P5) (%)	P4(50)	P4(43)	P4(94)	P4(71)
sending ARIA+ (%)	Rural(75)	Inner regional(74)	Major city(94)	Major city(49)

*Statistical significance codes: ***<0.001*; Cohen's h=.20 (small effect). *Abbreviations: ARIA+: Accessibility/Remoteness Index of Australia[20], P1: priority category 1 (most urgent); P5 priority category 5:(lower urgency). a.) One (<1%) missing priority category.*

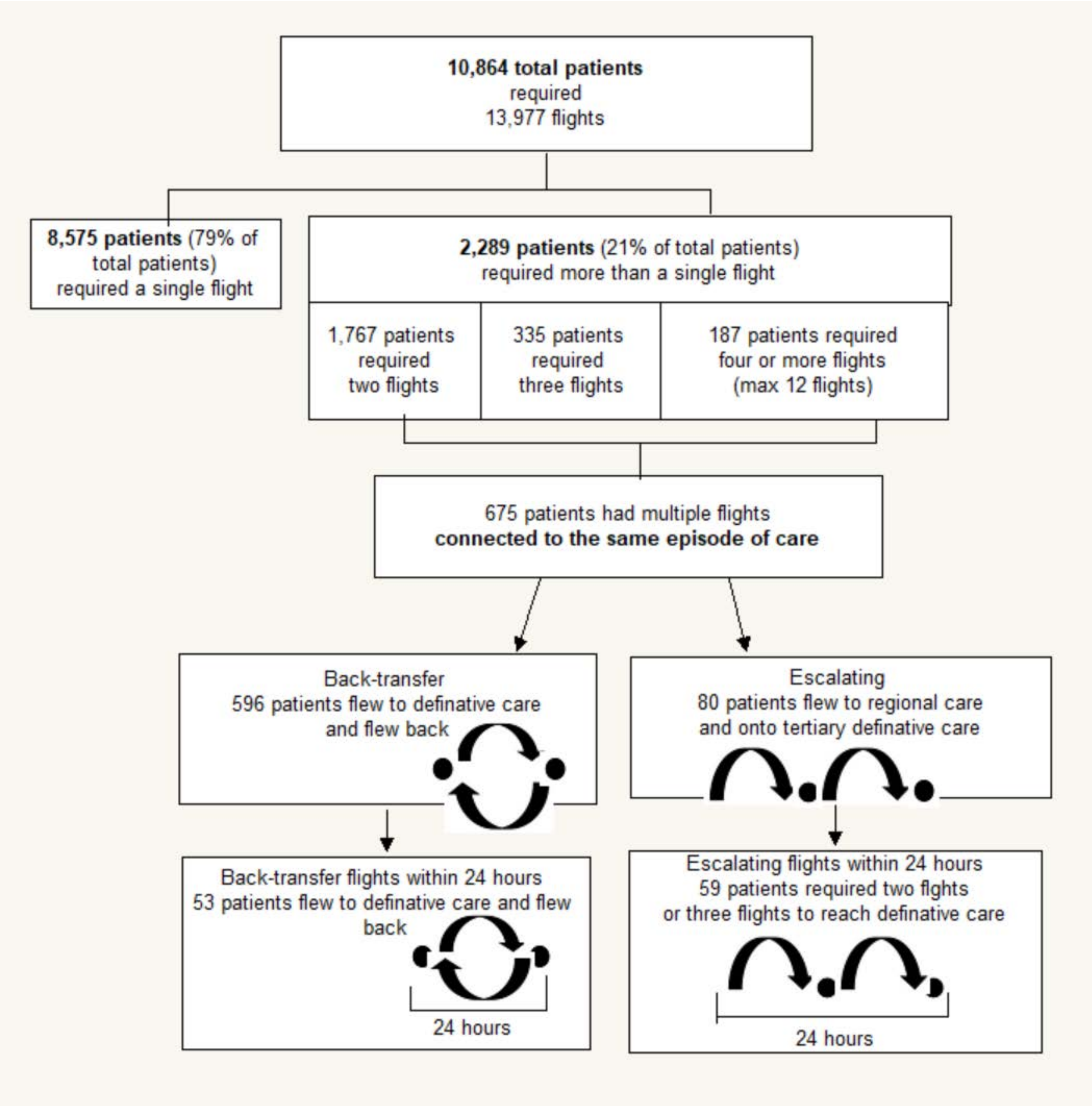
Supplementary S2. Overall summary of the referral pathways

Variable	Referral pathways Intraregional n=3536	OUT of region n=7776	INTO region n=2665	Study total N=13977
Patient				
Age years mean(sd)	41.1(23.8)	52.2(24.1)	51.1(28.2)	49.1(25.3)***
Female n(%)	1437(41)	3044(39)	1154(43)	5635(40)***
Aeromedical				
Task: IHT n(%)	2901(82)	7470(96)	2440(92)	12811(92)***
primary n(%)	599(17)	176(2)	170(6)	945(7)
non-hospital return n(%)	36(1)	130(2)	55(2)	221(2)
Asset: Fixed Wing n(%)	2345(66)	7453(96)	2444(92)	12242(87)***

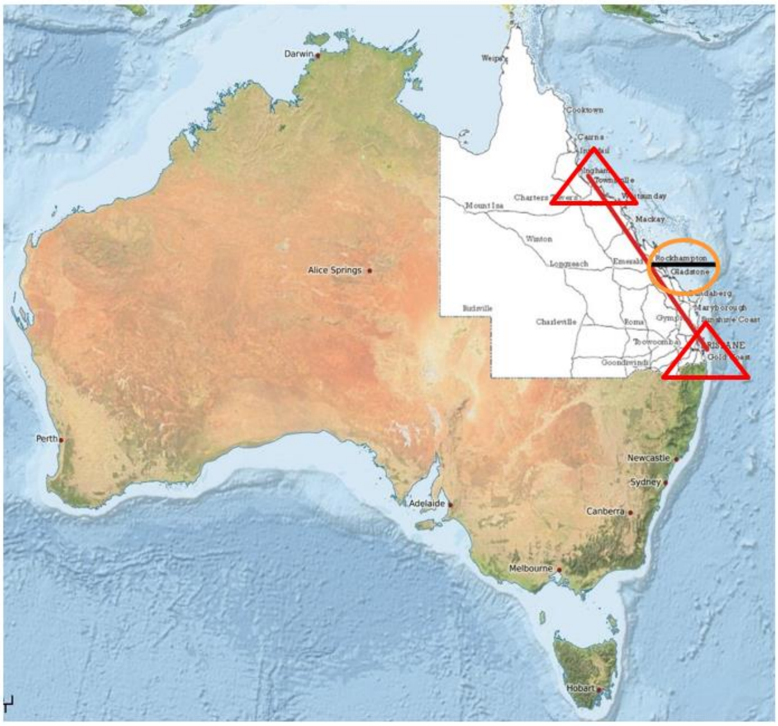
Asset: Rotor Wing n(%)	1002(28)	26(<1)	31(1)	1059(8)
Priority: P4 & P5 n(%)	1123(32)	5334(69)	2011(75)	8468(61)*
P4 &P5 Request-activation interval(hours) mean(sd) median(min-max)	10.1(18.0) 4(0-158)	22.1(25.1) 16(0-259)	27.8(32.6) 17(0-374)	21.9(26.7)*** 15(0-374)
Sending location/ department				
ARIA+ most common n(%)	Rural 3316(94)	Inner regional 6566(84)	Major City 1575(59)	Inner regional 6957(50)
Sending ED n(%)	166(5)	539(7)	69(3)	74(6)***
ICD most common n(%)	Appendicitis 25(15)	Myocardial Infarct 112(21)	Appendicitis 6(9)	-
LOS (hours) mean(sd)	2.9(2.2)	4.8(3.6)	3.1(3.0)	4.3(3.4)***
Sending hospital n(%)	2768(78)	7056(91)	2426(91)	12250(88)***
DRG most common n(%)	Digestive 271(10)	MI 1527(22)	Injuries 95(4)	-
LOS (days) mean(sd)	1.1(3.0)	3.2(5.9)	10.3(16.3)	4.1(9.2) ***
Receiving location/ department				
ARIA+ most common n(%)	Inner regional 3401(96)	Major City 7484(96)	Inner regional 2522(95)	Major City 7449(53)
Receiving ED n(%)	2738(77)	2017(26)	1752(66)	6507(47)***
ICD most common n(%)	Appendicitis 172(6)	Myocardial Infarct 77(4)	Stroke 53(3)	-
LOS (hours) mean(sd)	4.3(3.1)	1.7(1.8)	4.6(4.0)	3.6(3.3)***
Disposition: discharged n(%)	290(11)	79(4)	131(7)	500(8) ***
admit to hospital n(%)	2302(84)	1916(95)	1562(89)	5780(89)
transferred n(%)	131(5)	20(1)	47(3)	198(3)
LAMA n(%)	n.p	nil	12(1)	21(<1)
died in ED n(%)	n.p	n.p	nil	n.p
Direct hospital admission n(%)	759(21)	5621(72)	851(32)	7231(52)***
DRG most frequent n(%)	Vaginal birth 39(5)	Interventional cardiology 529(9)	Surgical followup 70(8)	-
LOS (days) mean(sd)	4.6(8.3)	8.8(12.7)	8.9(12.1)	8.4(12.3)***
Disposition: home n(%)	412(54)	4319(77)	560(66)	5291(73) ***
transferred n(%)	298(39)	857(15)	154(18)	1309(18)
died in hospital n(%)	17(2)	109(2)	62(7)	188(3)
other n(%)	32(4)	335(6)	75(9)	442(6)

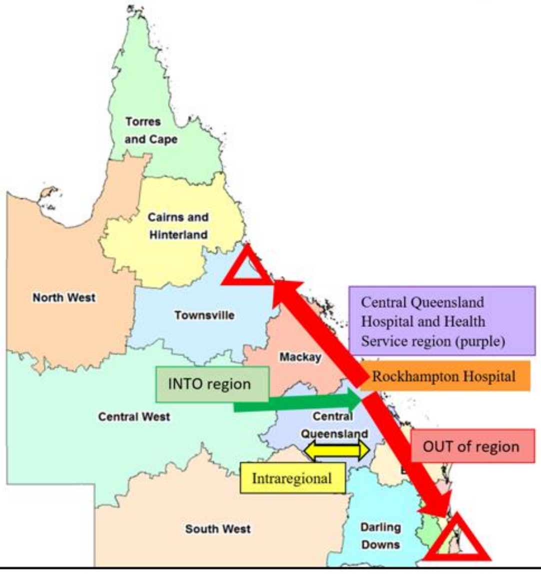
*Statistical significance codes: *<0.05, ***<0.001*; Cohen's d/h=.20 (small effect), d/h=.50 (medium effect), d/h=.80 or higher (large effect). *Abbreviations: ARIA+: Accessibility/Remoteness Index of Australia[20]; d: Cohen's d; ED: emergency department; h: Cohen's h; LOS: length of stay; LAMA: left against medical advice; MI: myocardial infarct, n.p: not presented (for patient sums <10), P4 & P5: least urgent priority categories. Missing data was subtracted from denominators (for missing data see Appendix 7).*

Supplementary S3. Multiple flights per person during the study period



Supplementary S4. Map of study region

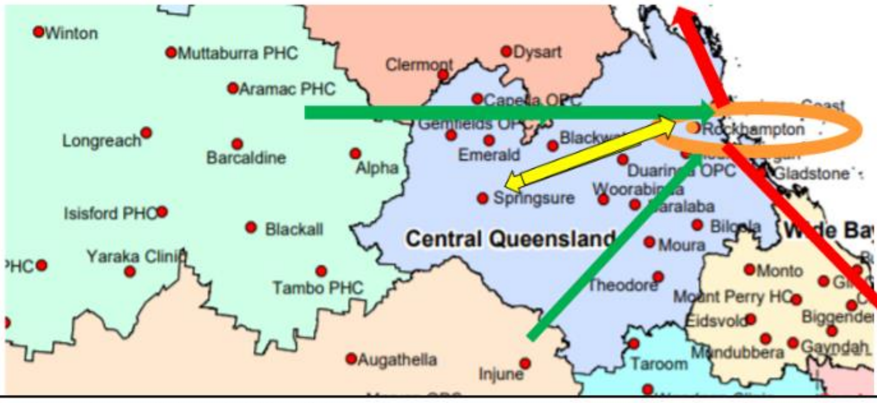




Legend: (Top image) Whitened outline: State of Queensland, Black underline: town of Rockhampton, Red line: flight path to tertiary facilities: Townsville to the north, Brisbane to the south (author approximated), and Red triangles: tertiary facilities, Orange circle: regional hospital. (Bottom image) Referral pathways Red arrows (OUT of region), Green arrows (INTO region), and Yellow arrows (Intraregional).

Source credit: (top image) http:www.eAtlas.org.au, (bottom image) http:www.qld.health.gov.au

Supplementary S5. Map of Central Queensland Hospital and Health Service region



Legend: Purple area: Central Queensland Hospital and Health Service region, Orange circles: regional hospital, Red dots: rural clinics and hospitals, Green arrows (INTO region), Yellow arrows (Intraregional).

Source credit: http:www.qld.health.gov.au

Supplementary S6. Queensland air ambulance priority categories (P1-P5)

Asset type	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5
Fixed wing: Rotor wing:	<u>Fixed wing:</u> 30 minutes during 0800-2000, 45 minutes during 2000-0800 <u>Rotor wing</u>: 15 minutes during 0800-2000, 30 minutes during 2000-0800.	1-3 hours All aircraft Day or night	3-6 hours All aircraft Day or night	6-24 hours All aircraft Day or night	24 hours All aircraft Day or night

Queensland Emergency Helicopter Network Tasking Guidelines (2011)[18]

Supplementary S7. STROBE statement

	Recommendation	Page No
Title and abstract	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
	(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2

Introduction

Background/rationale	Explain the scientific background and rationale for the investigation being reported	4,5
Objectives	State specific objectives, including any prespecified hypotheses	1,5
Methods		
Study design	Present key elements of study design early in the paper	5
Setting	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5,6
Participants	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	1,13
Variables	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7,8
Data sources/ measurement	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*7,8*
Bias	Describe any efforts to address potential sources of bias	10
Study size	Explain how the study size was arrived at	12
Quantitative variables	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8,9,10
Statistical methods	(*a*) Describe all statistical methods, including those used to control for confounding	14
	(*b*) Describe any methods used to examine subgroups and interactions	14
	(*c*) Explain how missing data were addressed	14
	(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	

	Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
	(*e*) Describe any sensitivity analyses	
Results		
Participants	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	12,15,16
	(b) Give reasons for non-participation at each stage	12
	(c) Consider use of a flow diagram	12
Descriptive data	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	15,16
	(b) Indicate number of participants with missing data for each variable of interest	36,37
	(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	*Cohort study*—Report numbers of outcome events or summary measures over time	15,16
	Case-control study—Report numbers in each exposure category, or summary measures of exposure	*NA*
	Cross-sectional study—Report numbers of outcome events or summary measures	*NA*
Main results	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	NA
	(*b*) Report category boundaries when continuous variables were categorized	15,16
	(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion		
Key results	Summarise key results with reference to study objectives	21,22
Limitations	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	23

Interpretation	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	23
Generalisability	Discuss the generalisability (external validity) of the study results	23
Other information		
Funding	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	24

Supplementary S8. Missing values in overall summary table

MISSING Variable	**MISSING** Referral pathway			Study total N=13977
	Intraregional n=3536	OUT of region n=7776	INTO region n=2665	
Aircraft type (e.g., FW, RW) n(%)	189(5)	297(4)	190(7)	676(5)
Aeromedical priority categories	14(<1)	41(<1)	8(<1)	63(<1)
P1 Request-activation interval	200(44)	36(10)	3(6)	243(28)
P2 Request-activation interval	180(28)	37(5)	12(9)	235(15)
P3 Request-activation interval	200(16)	60(5)	26(6)	286(10)
P4 Request-activation interval	99(9)	208(4)	117(7)	424(6)
P5 Request-activation interval	5(13)	48(7)	86(32)	139(14)

Abbreviations: FW: fixed wing aircraft; P1-5: aeromedical team activation priority categories (P1=most urgent, P5=least urgent); RW: rotor wing aircraft.

5.2 Additional thesis analysis A:

A.) Comparing patient and service outcome measures from aeromedical-only data and linked data

The comparison between the outcome measures of aeromedical-only and linked data were not included in the manuscript due to publishing constraints. The linked data variables are provided below. There were forty outcome measures of interest, categorised in nine main themes (Table A). Thirteen variables (indicated with a symbol *) were used in Table 1 of the publication. As discussed in chapter 2, measuring quality performance in the aeromedical environment is challenged by the complexity and interconnectedness of the emergency system, the variation between aeromedical system structures, and patients' high acuity and multiple comorbidities. Therefore, mortality in the framework was explored in four areas: in-hospital death, overall deaths (regional pathway differences), 0-7 days, and >1 year. Seven of the nine themes were used to describe balanced outcome measures in a quality framework (discussed in chapter 1). This study's previous examination of aeromedical-only outcome measures (discussed in chapter 4) used sixteen variables in five themes (italicized in Table A).

Table A. Patient outcomes and service variables; from analysis of linked data and aeromedical-only measures (italicized in blue font).

Main themes and variables	Data sources used for linkage (Aeromedical + ______)
Mortality	
Mortality in ED	+ ED source + death location/date
*Mortality in hospital	+ hospital source + death location/date
*Mortality after flight,	+ death date
Cause of death (ICD-10)	+ death cause
Referral Pathway	
Facilities in HHS boundary	+ hospital or ED origin and destination region
**Sending location & receiving location*	+ hospital or ED origin and destination location/facility name
Direction of retrieval from receiving (within HHS, leaving HHS, coming into HHS),	+ hospital or ED origin and destination location/facility and region
Patient demographics: *age, sex,* illness/injury type (ICD-10), procedures (DRG)	+ ED/ hospital source ICD/DRG
*Patient history (number of flights) over the study period	+ unique patient ID + ED/hospital/death sources
Journey type: Single one-way flights	+ single unique patient ID + ED/hospital/death sources
Multiple flights (e.g., primary rotor wing flight to regional hospital, onto IHT fixed wing to tertiary hospital)	+ multiple unique patient ID + ED/hospital/death sources + event date time
Round-trip flights (e.g., flight to tertiary, then back-transfer to home)	+ multiple unique patient ID + ED/hospital locations + event date time
Pick-up points along a journey (e.g., take-off in Rockhampton, land in Gladstone to pick up another patient, final destination Brisbane)	RFDS take-off/landing airfield and date time
Asset/ team type	
**Aircraft type (fixed wing or rotor wing)*	RSQ, QNETS, LRM, RFDS
Provider/ vendor (doctor input data, nurse input data)	RFDS=Nurse input, LRM=Doctor input, QNETS=Neonatal specialized teams
*Mission/ task type (primary, IHT, non-hospital return)	+ sources before flight/sources after flight (inclusion of/absence of)
Access to definitive interventions	

**Hospital/facility destination; tertiary, rural & regional*	+ destination ED/hospital name
Distance transported	+ destination ED/hospital name; 'as the crow flies'
Accessibility and frequency of service	
Day of week volume trends by aircraft/ task type	date by day of week
Monthly volume trends by aircraft/ task type	date by day of month
Yearly volume trends by aircraft/ task type	date by year
**Sending community remoteness index (ARIA+)*	sending ED/hospital name/location + ARIA+
Responsiveness of service	
Peak request for service periods	Request for service datetime frequency
Cancelled flights,	Task variable 'cancelled'
Advice calls prior to activation	Task variable 'advice'+ request for service date time
*Request-to-activation interval time,	Activation - request event time
Activation-to-at scene time interval	With patient or first contact -activation date time
Activation-to-handover time interval	Handover or arrive receiving facility - request date time
Request-to-handover time interval	Handover or arrive receiving facility - activation date time
Peak activation periods	Team activation date time frequency
Patient admission to facility	
*Admission via ED, direct to hospital,	+ ED or hospital sources
*Length of stay in ED or hospital	+ ED or hospital end time-start time
Patient disposition from facility	
*ED/ hospital discharge; home, admit to hospital, death, left against medical advice, transferred or death	+ ED or hospital disposition
Perceived urgency	
**Aeromedical priority categories (P1-P5)*	RSQ, QNETS, LRM, RFDS priority
Australian Triage Scale (ATS) (1-5)	+ ED ATS

*Abbreviations: ARIA+: Accessibility/Remoteness Index of Australia; ATS: Australasian Triage Scale; DRG: diagnostic-related groups; ED: emergency department; HHS: hospital and health service; ICD-10: International Classification of Diseases; LOS: length of stay; LRM: LifeFlight Retrieval Medicine; QNETS: Queensland Neonatal Emergency Transportation Systems; RFDS: Royal Flying Doctor Service; RSQ: Retrieval Services Queensland. Symbol key: *Main theme and variable used in Table 1 of publication 4.*

5.3 Chapter summary

This study explored aeromedical patient and service outcomes using linked data from aeromedical, ED, hospital, and death registry. The research contributes to overall understanding of the aeromedical patients' journeys, specifically in terms of flights per person and mortality after flight. The aeromedical quality framework accommodated existing the patient outcomes and service variables from linked data. This outcome aligned with the primary objective, which was to utilise patient data and service outcomes to explore how they can be used in an aeromedical quality framework. The supplementary material (S1-S3) in the publication and the Additional thesis analysis A, provide key results that are found in Table 1 of publication 4. Appendicitis was found to be the most common sending facility illness in two of the three the referral pathways, intraregional and 'INTO region'. Aeromedical retrieval of suspected appendicitis and acute abdominal pain is explored further in chapter 6, the fifth publication in the thesis.

5.4 Salient points

- This is the first published study of linked aeromedical data to ED, hospital, and death data in Central Queensland that has explored flights per person and mortality.
- The air ambulance quality framework can usefully be applied to air ambulance patients' experience and outcomes using linked data analysis.
- The air ambulance quality framework will help guide prehospital and in-hospital performance reporting.
- With variations between regional referral pathways, this knowledge will aid with planning within the local service.
- There were 13,977 flights for 10,864 patients, and 2,289 patients (21%) had multiple flights.
- Three aeromedical referral pathways were identified in the CQHH region: Intraregional, 'INTO region', and 'OUT of region'.
- Identification of referral pathway variations and gaps in service will help to recognise disparities and will be important to meet future community needs.
- The frequency of admission of rural patients with suspected appendicitis via the ED suggests access limitations of diagnostic imaging at rural hospitals.
- However, as there is no data to confirm aeromedical transfer due to lack of available imaging, it may also suggest transfer for further surgical opinion and or/ treatment.
- Mortality was selected in the framework column 'Patient outcome measures', as it was defined in chapter 3 publication 2, "a health state of a patient

resulting from healthcare" according to The Agency for Healthcare Research and Quality.

- There were 234 (2% overall) occasions of mortality 0-7 days after flight, of which 34% were cardiac-related.

Chapter 6. Results of appendicitis linked data: Air ambulance retrievals of patients with suspected appendicitis and acute abdominal pain: The patients' journeys, referral pathways and appendectomy outcomes using linked data in Central Queensland, Australia

Overview of the chapter

Chapter 6 continues to build understanding of aeromedical and patient outcomes from linked data. This is the second study addressing thesis aim 3.

- aim 3: To explore the aeromedical patients' journeys in Central Queensland using linked data.

This study builds upon findings of the most common illness sent from rural facilities in the intraregional and 'INTO region' referral pathways in chapter 5, suspected appendicitis. A new term and assessment of aeromedical referral pathway is introduced, called the '*referral progression pathway*', and is based on hospital capability levels in Central Queensland (i.e., rural-level to regional-level, rural-level to tertiary-level, regional-level to tertiary-level). Exploring referral progression pathways can identify secondary overtriage (i.e., when available regional capability-level hospitals are bypassed and referred to tertiary facilities). Aeromedical service time interval requests from service-to-activation are explored with outcomes of appendectomy severity. Figure A. summarises the main aims and outputs from the thesis and indicates the position of this chapter within the thesis.

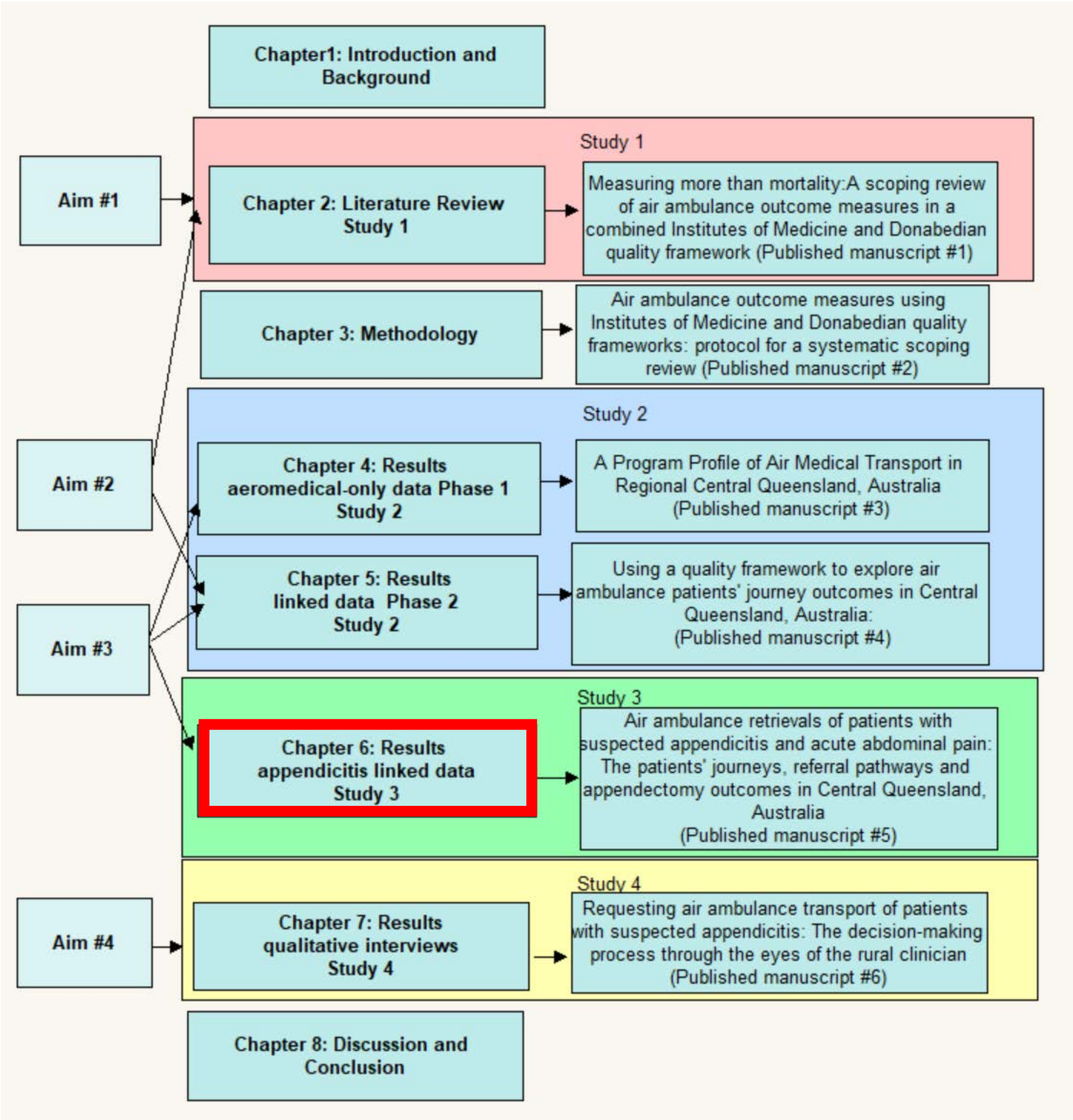


Figure A. Conceptual model of the thesis aims and outputs

Study aims 1-4 are in the boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a red box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

This chapter contains the following manuscript that has been published in a peer-reviewed journal, relevant to aeromedical retrieval, and is inserted as a published .pdf in the format required by Australasian Emergency Care:

This chapter comprises a published manuscript. It is inserted as published. The citation is:

Edwards, K.H., Edwards, M.T., Franklin, R., Khanna, S., Kuhnert, P.M., R.C., Jones. (2022). Air ambulance retrievals of patients with suspected appendicitis and acute abdominal pain: The patients' journeys, referral pathways and appendectomy outcomes using linked data in Central Queensland, Australia. *Australasian Emergency Care*. https://doi.org/10.1016/j.auec.2022.07.002

6.1 Manuscript

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Research Paper

Air ambulance retrievals of patients with suspected appendicitis and acute abdominal pain: The patients' journeys, referral pathways and appendectomy outcomes using linked data in Central Queensland, Australia☆

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ABSTRACT

Introduction: Acute appendicitis is the most common cause of acute abdominal pain presentations to the ED and common air ambulance transfer. Aims: describe how linked data can be used to explore patients' journeys, referral pathways and request-to-activation responsiveness of patients' appendectomy outcomes (minor vs major complexity).

Methods: Data sources were linked: aeromedical, hospital and death. Request-to-activation intervals showed strong right-tailed skewness. Quantile regression examined whether the longest request-to-activation intervals were associated with appendicitis complexity in patients who underwent an appendectomy.

Results: There were 684 patients in three referral pathways based on hospital capability levels. In total, 5.6 % patients were discharged from ED. 83.3 % of all rural origins entered via the ED. 3.8 % of appendicitis patients were triaged to tertiary hospitals. Appendectomy patients with major complexity outcomes were less likely to have longer request-to-activation wait times & had longer lengths of stay than patients with minor complexity outcomes.

Conclusions: Linked data highlighted four aspects of a functioning referral system: appendectomy outcomes of major complexity were less likely to have longer request-to-activation intervals compared to minor (sicker patients were identified); few were discharged from EDs (validated transfer); few were triaged to tertiary hospitals (appropriate level for need), and no deaths relating to appendectomy.

Introduction

Acute appendicitis is the most common cause of acute abdominal pain presentations to the emergency department (ED) [1,2] and the most frequent air ambulance transfers for ED presentation from rural origins in the Central Queensland region, Australia [3]. It is in the top seven emergency general surgery (EGS) procedures which account for 80 % of all surgical volume, complications, death and costs in America [4]. However, given the frequency of acute appendicitis and acute abdominal pain, little is known about outcomes of EGS [5] patients' aeromedical journeys (where they originated, the destination, time that it took and their disposition) [3]. In this study, aeromedical patients' journeys are defined as: the integrated, continuum of care that spans multiple settings; prehospital and hospital based pre-flight, aeromedical transport, receiving ED, hospital and disposition [3].

The primary aim of this study was to describe how linked data can be used to explore EGS [5] patients' aeromedical journeys. The secondary aim was to describe how linked data can be used to examine referral pathway outcomes (i.e., clinicians refer patients in paths toward higher levels of care). Referral pathway outcome attributes include: origin location (rural-level or regional-level), admission pathway (via ED or direct admission to hospital), receiving

☆ The authorship listing conforms with the journal's authorship policy and all authors are in agreement with the content of the submitted manuscript.

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hospital service capability type (regional-level or tertiary), initial receiving ED diagnosis, and patients' appendectomy outcomes coded as major or minor complexity (i.e., severe vs not severe) by request-to-activation time intervals.

Queensland uses a distributed, medically-resourced system [6] (Appendix 1, Appendix 2). Highly resourced, tertiary-care centres are located in larger, metropolitan areas (e.g., Brisbane, Gold Coast, and Townsville) [6]. Moderately resourced, regional-level capability medical centres [6] are distributed across Queensland's hospital districts (e.g., Rockhampton Hospital in Central Queensland). Yet these district centres may lack neurosurgical, interventional radiology, interventional cardiology and dedicated paediatric critical care services. Other lesser resourced, rural-level capability medical centres may have severely limited or absent diagnostic radiology, and general surgical services [6]. Because of these differing levels of available medical resources, there are well-established referral pathways for interhospital transfer of patients. To facilitate interhospital transfers (IHTs) across large distances, a centrally co-ordinated aeromedical system exists; Retrieval Services Queensland [3]. In Central Queensland Hospital and Health Service (CQHHS) region (or district), appendectomies can be performed at the main regional-level capability hospital with fully capable EGS services. The closest tertiary hospitals are 750+ kilometres from the CQHHS jurisdiction boundary; approximate eight hour ground transport time [3].

When procedures like appendectomies bypass available regional capability-level hospitals and are performed at tertiary hospitals, it places an unnecessary burden on the emergency system [7]. Often called secondary overtriage (SO), bypassing regional capability-level hospitals is a wasteful use of expensive and limited resources [8,9], has been linked to reduced efficiency in tertiary EDs and takes patients far from their community support [9]. While studies have examined SO for trauma [10], none have explored SO for EGS in referral service levels, along routes defined in this study as *'referral progression pathways'* (i.e., rural-level to regional-level; rural-level to tertiary-level; regional-level to tertiary-level).

Acute abdominal pain can present as part of a spectrum of conditions; some benign and others surgical emergencies [11]. Patients' physical exam findings and laboratory test results are often non-specific and nondiagnostic, making a definitive diagnosis very difficult [11]. Yet, a delayed or missed diagnosis of acute appendicitis may result in perforation with associated long-term morbidity [12]. Ultrasound and computerized tomography (CT) are two examples of common diagnostic modalities used for diagnosing acute appendicitis [13].

Currently in rural Australian communities, there is low availability and accessibility of diagnostic imaging [14]. A Queensland Health (the State's public health provider) protocol for IHTs requires direct hospital admission for stable patients, unless they have "an undifferentiated condition requiring specific investigations" [15]. Therefore, rural aeromedical IHT patients requiring diagnostic imaging, will enter a receiving hospital through the ED. However, aeromedical IHT's that result in a discharge from the ED, may be considered a potentially avoidable transfer [16]. While IHT's are necessary, due to the lack of diagnostic modalities in rural facilities, some transfer may represent inefficient use of resources and needs further exploration [17].

Time delays are an inherent risk of IHT's [18,19]. Delays in acute appendicitis diagnosis and surgical interventions may lead to higher complications and poor patient outcomes [19]. Nonetheless, little is known about the aeromedical time interval from request for service to activation of aeromedical teams for transport of patients with suspected appendicitis and their subsequent outcomes. Understanding the time interval range (min-max) is a starting point to identify quality service provision and to help guide future improvement planning.

Methods

This is a descriptive, retrospective cohort study of patients retrieved on a dedicated, medical-specific aircraft either: a) between facilities within CQHHS; b) departed from a facility within CQHHS to a hospital outside the district; or c) arrived into CQHHS from a facility outside the district. Data sources from aeromedical, ED and hospital were collected from 1 January 2011 until 31 December 2015. Death registry data covered the period from 1 January 2011 until 30 June 2019. Human research ethics approval was given by Central Queensland Hospital and Health Service HREC (CQC/16/HREC/8) and the Queensland Department of Health (RD007591).

This study builds upon two prior studies which found limitations of aeromedical-only patient and service data which were unlinked to hospital or death data [20–22]. One study described state-wide aeromedical-only data and the other CQHHS aeromedical-only data. These prior studies used data sources during the same time period as the current study, but only consisted of: adult, pediatric and neonatal (i.e., Queensland Newborn Emergency Transport Service) aeromedical patient and service records, as the data was unlinked to hospital and death data during the time of publication. The data was provided by Queensland Health, the State's public health provider [22] and managed by Retrieval Services Queensland (RSQ). The current study has added data from contracted aeromedical providers; LifeFlight Retrieval Medicine and the Royal Flying Doctor Service-Queensland Division and has linked with data from Emergency Department Information Systems (EDIS), Queensland Hospital Admitted Patient Data Collection (QHAPDC), and the Queensland Death registry. This current study is a sub-study from a core linked data set which described 13,977 linked aeromedical patient episodes in Central Queensland [3]. Due to the high frequency of appendicitis-related IHT's in CQHHS, the authors chose to explore its occurrence further for this current study.

Data sources were linked by a unique patient identifier. Data linkage utilized deterministic and/ or probabilistic methods [3]. Each patient was given a unique patient ID [3]. Record linkage used date and time, from each unique identifier, to match the end of one care episode to the start of the next care episode.

The CQHHS district covers a geographical area of 114,000sq km with a resident population of 226,273 (estimated) during the study period [22] (Appendix 1, Appendix 2). Rockhampton Hospital functions as the main regional-level medical center for the whole CQHHS district and accepts patients from sixteen small, rural hospitals and clinics from within its own jurisdiction boundaries, and from two large, adjacent rural/ remote health service districts (Central West Hospital and Health Service (HHS), South West HHS) which lack both regional-level and tertiary hospital services [22]. The health service setting and capabilities in CQHHS were previously described in detail [20].

Samples were selected using the International Classification of Diseases (ICD), Australian Modification, tenth revision [23] (ICD-10-AM) (K35, R10) illness codes and from the diagnosis-related groups (DRG), refined to represent the Australian hospital service (version 7.0) [24] (DRG-AR) (G66, G70, G07) (Table 1). At sending facilities, patients given a preliminary appendicitis diagnosis (K35) were labelled, 'Appendicitis'. Patients given a preliminary acute abdomen differential diagnosis (R10, G70 or G66) were labelled, 'Acute abdomen', and patients given a preliminary diagnosis that was neither acute abdomen nor acute appendicitis, but ultimately diagnosed with appendicitis at the receiving hospital were labelled 'NOT appendicitis NOR acute abdomen'.

Patients' appendectomy outcomes were subdivided by two codes: minor complexity and major complexity. According to the Australian Institute of Health and Welfare, patients' appendectomy outcome with major complexity (DRG-AR code G07A) was defined as: "with malignancy or peritonitis or with catastrophic or severe

Table 1
Sending facility illness code selection by ICD-10-AM and DRG-AR.

Code system	ICD-10-AM		DRG-AR		
Main topic	Symptoms and signs of the digestive system and abdomen	Diseases of the digestive system	Diseases and disorders of the digestive system		
Subset topic (code)	*Acute abdomen* (***R10***)	*Acute appendicitis* (***K35***)	*Abdominal pain* (***G66***)	*Other digestive disorders* (***G70***)	*Appendectomy (major complexity)* (***G07A***) *(minor complexity)* (***G07B***)

Note: Australian versions ICD-10-AM [23] and DRG-AG [24] for suspected acute appendicitis and acute abdominal pain are used.

complications and/or comorbidity" [24] and patients' appendectomy outcome with minor complexity (DRG-AR code G07B) was defined as: "without malignancy or peritonitis without catastrophic or severe complications and/or comorbidity" [24].

Preliminary and uncertain diagnoses codes relating to abdominal pain were included in the search due to the ICD-10 rules governing uncertain diagnoses (e.g., probable, likely, possible, consistent with, suggestive of, indicative of, appears to be) must be made and managed clinically as if the diagnosis was confirmed [25] (Table 1). Further, a diagnosis documented as uncertain at the time of discharge will be coded as if it were confirmed [25]. In addition, if there are more than one possible diagnosis for a particular condition, even though the patient remains somewhat undifferentiated, clinicians are required to document a diagnosis that is "most likely or probable, based on clinical circumstances and sound professional judgement" [26]. For these reasons, patient episodes characterized as acute abdominal pain, abdominal pain and 'other digestive disorders' were included in this study.

Inclusion criteria for the study were patient data retrieved/transported on a dedicated, medical-specific helicopter or fixed-wing aircraft over the period 1 January 2011 until 31 December 2015, in referral pathways into, within or out of the CQHHS region, and illness codes: ICD-10-AM R10, K35, DRG-AR G66, G70, G07A&B. All patient age groups and genders were included. The study did not include road tasks, advice calls, cancelled tasks or search and rescue missions.

Aeromedical service interval was determined by the elapse time from the request for service to the activation of aeromedical teams, referred to as 'request-to-activation'. Hospital service and resource capability levels (rural, regional, tertiary) are defined in this study as; rural-level facilities broadly lack general surgery services and limited diagnostic modalities while regional-level facilities lack interventional radiology, cardiology, neurosurgical and other specialist services. Retrieval tasks which had origins at rural properties or aged-care (non-hospital) facilities were defined as 'primary' tasks. Definitive diagnosis was defined by receiving facility DRG or ICD code prior to discharge. Presentation of the study followed STROBE guidelines to ensure adequate reporting [27]. (Appendix 4).

A statistical analysis of the data was conducted to examine whether severity of patients' appendectomy outcomes (i.e., major complexity vs minor complexity) varied across age categories, gender, aeromedical characteristics and sending and receiving facility logistics. Chi-square contingency tests were used to explore relationships between patients' appendectomy outcomes (major complexity vs minor complexity) and other categorical variables. Yates correction for continuity was used where appropriate. For normally distributed variables such as length of hospital stay, Welch's t-test examined whether the average value differed between high and low complexity episodes. Kruskal-Wallis rank sum tests were used for continuous variables that were not normally distributed. To examine the request-to-activation interval, quantile regression was used to evaluate factors affecting the likelihood of very long intervals. Quantiles 0.80, 0.85 and 0.90 were analyzed. A summary of missing data is provided (Appendix 3). A p-value of < 0.05 was considered statistically significant. Cohen's d was used to represent the effect size of the difference between two means [28]. Cohen's h is a measure of distance between two proportions [28]. Larger distances represents larger effects [28]. Reference values consist of 0.20 (small effect), 0.50 (medium effect), 0.80 or higher (large effect) [28]. The R programming language (2021–05–18; version 4.1.0, The R Foundation for Statistical Computing) was used for data pre-processing, cleaning and visualization. The R package 'quantreg' (2021–06–06; version 5.86) was used for quantile regression analysis, the R package 'effsize' (2020–10–05; version 0.8.1) was used for Cohen's d effect size analysis and the R package 'pwr' (2020–03–16; version 1.3–0) was used for Cohen's h effect size analysis.

Results

The core linked dataset consisted of 13,977 aeromedical patient episodes [3] of which 684 patients (4.9 % of core dataset) were suspected appendicitis and/or acute abdominal pain episodes identified at receiving facilities (Fig. 1).

The patients' journeys

The sending preliminary diagnostic codes were organised into three groups (Fig. 2). The first group, acute appendicitis (32 patients, 4.7 % of study total), were all from rural sending facilities of which half entered the receiving facility via the ED and half were directly admitted to the hospital. Appendicitis was the definitive diagnosis in the admission path via the ED with twelve patients (75.0 % via ED total) compared with two patients (12.5 % of direct admission total) via direct hospital admission path (Fig. 2).

The second group, acute abdomen sending codes from the sending facility, was the largest group with 629 patients (92.0 % of study total). For acute abdomen codes from rural hospital origins (556 patients, 88.4 % acute abdomen total), of these 465 patients (82.0 % acute abdomen, rural hospital origin total) were flown to regional-level hospitals, of which 423 patients (91.0 %) entered via the ED, 196 patients (46.3 %) received an initial appendicitis diagnosis. All regional-level hospital transfers went to a tertiary hospital (Fig. 2).

In the third group, 'Not acute appendicitis nor acute abdomen', nine patients (1.3 % of the study total) were on primary tasks which lacked sending hospital diagnostic codes (Fig. 2). Fourteen patients (2.0 % of the study total) had DRG-AR codes related to; female reproductive disorders (N6), hepatobiliary disorders (H6), kidney/ urinary (L6), gastrointestinal (G6) and sepsis (T6) (Specific codes not given for patient privacy, due to small sample size). Twelve patients were sent from rural facilities and two patients from regional-level facilities.

Receiving admission pathway and initial appendicitis diagnosis

The total rural origin flights (609 patients, 89.0 % of the study total) that entered the receiving facility via the ED were 507 patients (83.3 % of rural origin flights). Overall, patients entering the receiving facility via the ED (rural and regional origins), 505 patients were admitted (92 % of total entering via ED) and 31 patients (5.6 % of total entering via ED) were discharged from the ED with a non-

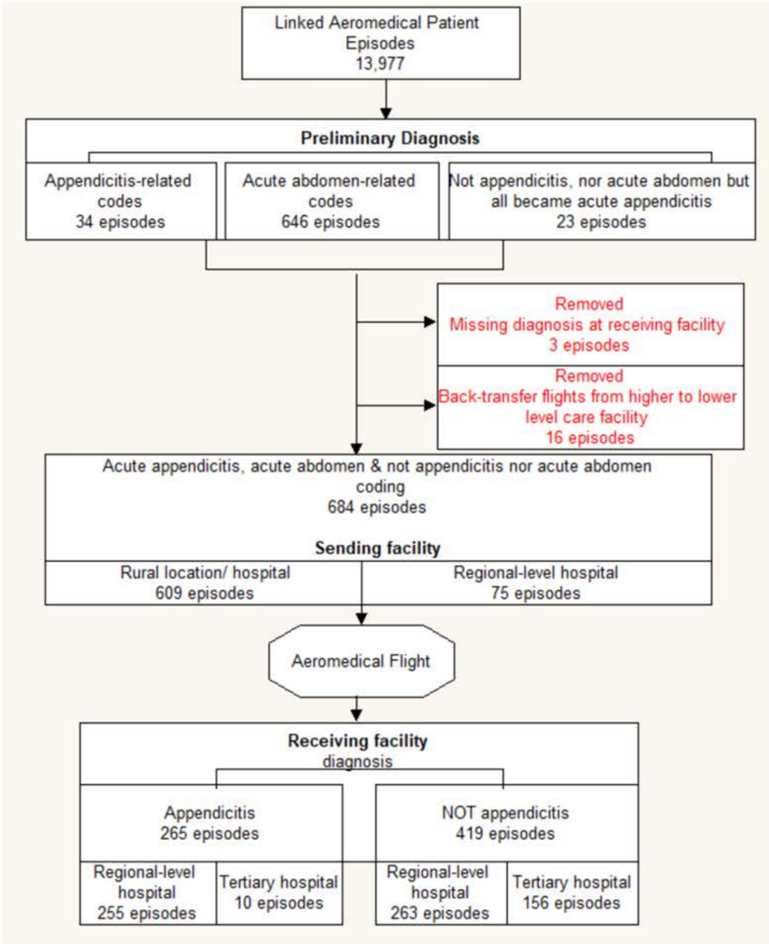

Fig. 1. Flowchart mapping patient journeys (linked data total from prior study (top box). Red font indicates episodes which were removed and why). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

appendicitis diagnosis. The study identified acute appendicitis diagnosis in 265 patients (38.7 % of the study total). The top three most common receiving facility diagnoses that were 'NOT acute appendicitis' (419 total patients, 61.4 % study total) were: 1.) non-perforated diverticular disease of intestine (82 patients, 19.5 %), 2.) unspecific intestinal obstruction (67 patients, 15.9 %), 3.) non-traumatic perforation of intestine (56 patients, 13.3 %).

Three referral pathways

Three referral pathways emerged: rural-level to regional-level hospital; rural-level to tertiary hospital (i.e., bypassing regional-level hospitals); and regional-level to tertiary hospital (Table 2). The difference between referral progression pathways in the proportion receiving an appendicitis diagnosis was significant (χ^2= 98.9; df=2, p < 0.001).

Definitive appendicitis diagnosis at receiving facilities

Of the total 265 patient episodes of acute appendicitis at receiving facilities, 30 patients (11.3 %) bypassed the ED and were directly admitted to the hospital for an appendectomy, of which 19 patients (63.3 %) had minor complexity outcomes and 11 patients (36.7 %) had major complexity outcomes (Fig. 3). One patient died 2–3 months after hospital admission date from disease of the liver (0.4 % of acute appendicitis total), and two patients died > 1 year after hospital admission date from malignant cancer and external causes (0.7 % of acute appendicitis total).

Following transfer, 235 patients with a preliminary diagnosis of acute appendicitis were received via the ED. Three patients were discharged from the ED (1.3 %) with a diagnosis other than appendicitis and the remaining 232 patients (98.7 %) were admitted to the hospital. Of the patients admitted to hospital, 151 patients (65.1 %) had an appendectomy and 81 patients (34.9 %) did not undergo an appendectomy (Fig. 3). Of the 151 patients who underwent an appendectomy, 108 (71.5 %) had minor complexity outcomes and 43 patients (28.5 %) had major complexity outcomes (Table 3). The proportion with major complexity outcome cases in males (35 patients, 81.4 %) was significantly higher than it was in females (8 patients, 18.6 %) (χ^2 = 6.7, df = 1, *p* 0.009) with medium effect size differences (Cohen's h effect size 0.53) between males and females

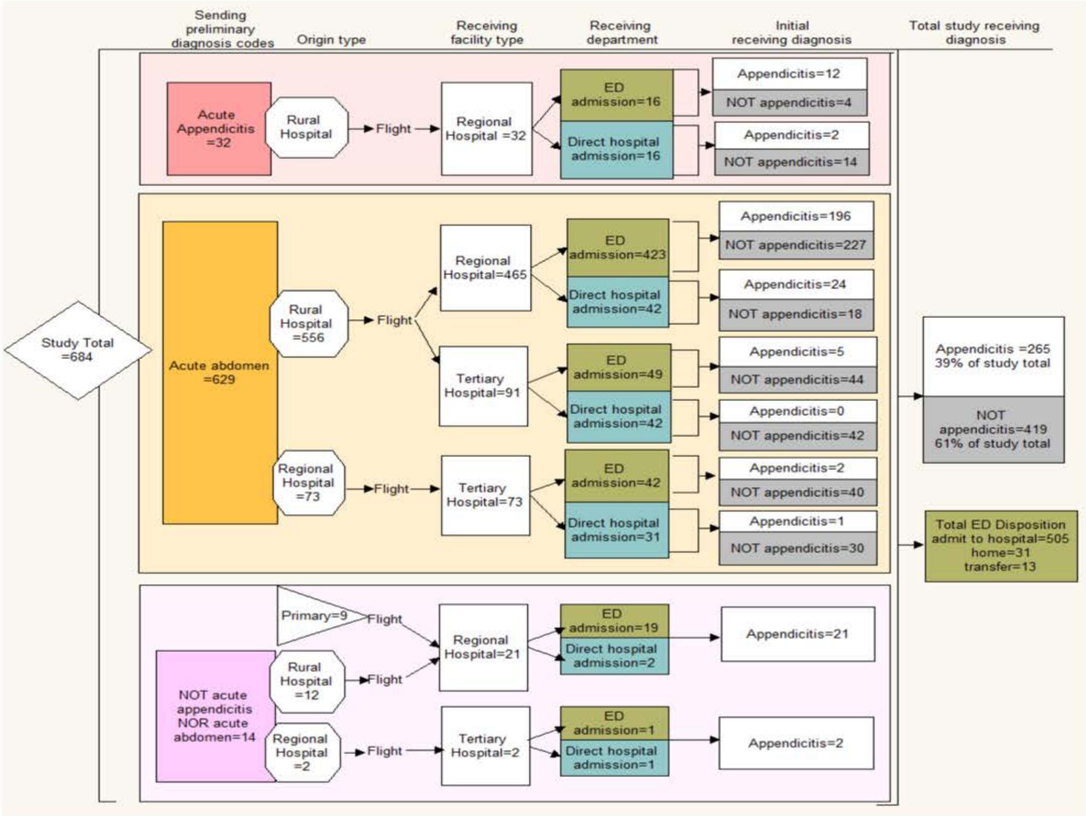

Fig. 2. Aeromedical referral pathways organised by sending facility preliminary diagnosis. (The top red pathway illustrates the pathway for patients with a preliminary acute appendicitis ICD code. The yellow pathway represents patients with preliminary acute abdomen ICD code. The lower pink pathway represents patient without acute appendicitis nor acute abdomen preliminary diagnosis). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

with major complexity outcomes. Overall, the sending facility length of stay (LOS) average was 0.4 days (9.6 h) and was not different between groups. However, the receiving facility average LOS for patients who underwent an appendectomy and had a major complexity outcome was 4.2 days, compared to the minor complexity outcome group, who had an average LOS of 2 days ($t = -3.88$, $df = 44.68$, $p < 0.001$), with a large effect size difference (Cohen's d effect size 0.83).

The median length of time from request-to-activation of aeromedical teams for transporting patients who received an appendectomy via the ED entry pathway was 1 h. For this group, request-to-activation times ranged from zero to 26.7 h. Furthermore, the median request-to-activation time for patients who received an appendectomy and had either a minor or major complexity outcome, was 1 h. However, the max range of request-to-activation times for patients who had a minor complexity outcome was 26.7 h compared with the max range of 11.4 h for patients who had a major complexity outcome (Table 4). The time interval distribution had a skew of 2.34 and a heavy right tail kurtosis of 5.87. Quantile regression found major complexity outcomes were significantly less likely to be in the long request-to-activation interval in the 85 % and 90 % tails, but there was no significant difference in the 80 % tail; an expected shift given the median intervals were the same for both complexity groups. As Table 4 shows, half of the minor complexity cases were activated within 1.6 h, but the major complexity cases were half activated in 1.1 h. For every quantile shown, the major complexity values were consistently lower than the minor complexity outcome values.

Discussion

Linked data could be used to explore EGS patients' aeromedical journeys. Appendectomy patients with major complexity outcomes were less likely to have long wait for request-to-activation than for appendectomy patients with minor complexity outcomes. Timely transfer of acute abdominal pain and suspected appendicitis has been known to reduce major complex postoperative outcomes [29], with these linked data findings showing that retrieval teams were more likely to be activated sooner for those patients which ended up being diagnosed as appendectomy with major complexity outcomes. This linked data finding is the first of four indications of an efficient functioning referral system; sending facility clinicians and the aeromedical service identified a more urgent, sicker patient presentation and responded timely to patient needs. The value of the study was in exploring how linked data can be used to explore the EGS patients' aeromedical journeys and evaluate the responsiveness of the service to the urgency of each case. Neither is possible without

Table 2
Referral progression pathway and appendicitis diagnosis totals.

Referral progression pathway	Patient episodes n (% study total)	Appendicitis diagnosis n (% appendicitis total)
Rural-level to Regional-level hospital	518(75.7)	255(96.2)
Rural-level to Tertiary hospital	91(13.3)	5(1.9)
Regional-level to Tertiary hospital	75(11.0)	5(1.9)

data linkage. We recommend the use of linked data to compare referral pathway variations over time.

The second linked data finding which indicates an efficient functioning referral system is that of all patients entering the receiving facility via the ED, very few were discharged to home. This ED disposition rate is below the findings in an American study of acute abdominal pain [30]. The results may indicate clinical necessity for the patients to fly toward higher levels of care and low potentially avoidable transfers [16]. Efficient use of limited resources, like air ambulance transport, is important to the overall sustainability of the referral service. Clinicians at the sending facilities correctly matched patient presentation and need with available services and resources at the receiving hospital. We recommend future linked data studies explore the reasons for ED discharge after aeromedical retrieval to further improve efficient use of limited resources.

Linked data highlighted referral structures designed to provide efficient and appropriate levels of service and resources, called *referral progression pathways*. For patients with an initial appendicitis diagnosis, the majority were sent (triaged) appropriately in the rural-level to regional-level pathway and low secondary overtriage to tertiary facilities. However, it's unknown the circumstances of why patients with a definitive appendicitis diagnosis were triaged to tertiary facilities. For example, it may have been the patients' preference, weather-related flight restrictions, and unavailable beds at the regional-level hospital or the sending clinician misdiagnosed appendicitis. If misdiagnosis was the reason, the rates are well below a recent study of referrals from general practitioners (i.e., lacking access to CT; similar to rural clinicians in our study) which they found 18.9 % of referred acute abdominal pain pediatric patients were ultimately misdiagnosed with appendicitis [31]. This is a third linked data indicator of an efficient functioning referral system. Appropriate referral progression pathways of hospital service and resources were identified for the majority of appendicitis patients. Finally, there were no deaths relating to appendicitis. We recommend further referral progression pathway research of linked data among the six other high frequency emergency general surgery procedures: partial colectomy, small-bowel resection, cholecystectomy, operative management of peptic ulcer disease, lysis of peritoneal adhesions and laparotomy [4]. Further review of the common pathways of these pathologies may increase the overall health care systems' service provision quality, in measures of efficiency and help future service planning.

Our study found majority of all rural origin retrievals entered the receiving facility via the ED, rather than direct admission to hospital

Table 3
Baseline characteristics of appendectomy patients via ED admission pathway.

Variable	Appendectomy via ED admission pathway		Study total N=151
	minor complexity n=108	major complexity n=43	
Patient			
Age years mean(sd)	28.5(13.8)	31.4(17.4)	29.4(14.9)
Sex female n(%)	46(42.6)	8(18.6)	54(35.7)*
Aeromedical			
Request-activation interval(hours) median (min-max)	1(0-26)	1(0-11)	1(0-26)
Sending facility/ location			
LOS (days) mean(sd)	0.4(0.4)	0.4(0.3)	0.4(0.4)
Receiving facility pathway			
LOS (days) mean(sd)	2(1.0)	4.2(3.6)	2.6(2.3)***
Disposition:			
home n(%)	108(100)	39(90.7)	147(97.4)
transferred n(%)	nil	3(6.9)	3(1.9)
change in care n(%)	nil	1(2.3)	1(<1)

Statistical significance codes: * <0.05, *** <0.001; Effect size codes; Cohen's d/h=.20 (small effect), d/h=.50 (medium effect), d/h=.80 or higher (large effect). Abbreviations: LOS: length of stay; sd: standard deviation. Note: Missing data was subtracted from denominators (missing data Appendix 3).

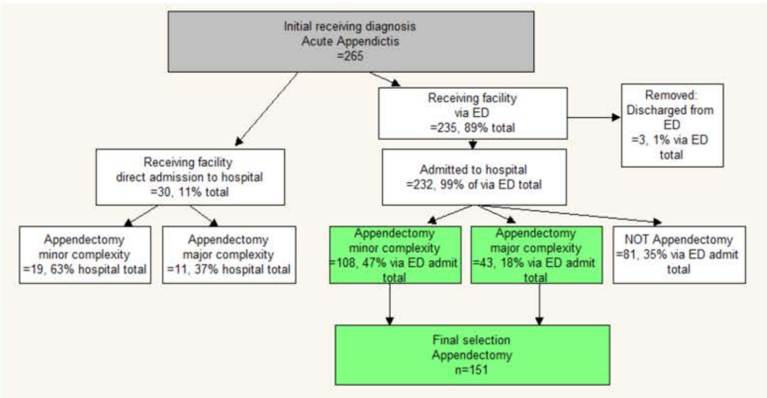

Fig. 3. Initial appendicitis diagnosis at receiving facilities (grey box). (Admission path was either direct admission to hospital (left side/arrow) or through the ED (right side/arrow). The boxes in green highlight selected appendectomy cases). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 4
Quantile of request-to-activation intervals for patients' appendectomy outcomes minor complexity versus major complexity.

Quantile of request-to-activation interval	Minor complexity value (Hours)	Major complexity value (Hours)
0.5 (median)	1.6	1.1
0.6	2.3	1.2
0.7	3.5	1.4
0.8	5.8	4.0
0.9	10.6	6.0
1.0 (maximum)	26.7	11.4

for surgery; suggesting access limitations of diagnostic imaging in rural hospitals [14]. This has implications for health outcomes, as the ongoing reliance on aeromedical retrieval for diagnostic confirmation may delay treatment, remove patients from their community support, and decrease timely clinical reflective practice and autonomy of rural providers [32]. Future solutions may include increased access to diagnostic modalities, such as ultrasound and associated training, upskilling or telehealth to improve diagnostic efficiency [33]. We recommend further exploration of the supports and barriers for rural clinicians and explore diagnostic modality uses such as hours of service and the process of requesting aeromedical services with patients for suspected appendicitis.

Patients with suspected appendicitis (ICD-10-AM code K35) at the sending facility received a diagnosis of acute appendicitis in less than half of the patients. Alternatively, patients sent with differential diagnosis of acute abdominal pain (ICD-10-AM code R10 or DRG AR code G66 or G70) had acute appendicitis in just over one third of patients, which were similar rates to a recent study of children in Spain [34]. Therefore, based on this finding, we recommended that future studies include all of the four acute abdominal pain and appendicitis codes; (ICD-10-AM: R10 and K35) and (DRG AR: G66 and G70).

Appendectomy occurred in more than half of appendicitis diagnoses at the receiving ED. This attests to the diagnostic challenges in the patient presentation; for regional-level ED clinicians, with access to diagnostic modalities, misdiagnosis may still occur until definitive surgical intervention [11]. Of the total appendectomy patients that had a major complex postoperative outcome, this finding was within range found in a recent review study [35]. Males were over represented in this group. Poor postoperative outcomes may be attributed to higher preoperative risk factors, fewer contact with primary healthcare which results in more advanced disease progression prior to surgery [36]. Surprisingly, the sending facility lengths of stay were similar between appendectomy patients who had either major or minor complexity outcomes. This may be due to the obligatory time for sending clinicians to triage, perform a thorough physical exam & history, and engagement with the retrieval service at the receiving hospital. We recommend further exploration of the rural clinicians' perspectives in requesting aeromedical retrieval for suspected appendicitis to help identify their strengths and barriers in the regional-level emergency care system, as the findings have potential to improve service provision. As expected, appendectomy patients who had major complexity outcomes had significantly longer postoperative lengths of stay at receiving hospitals, compared with those patients with minor complexity outcomes. These findings may help hospital bed management and staffing models at receiving facilities to allow for longer bed occupancy for appendectomy patients with major complexity outcomes.

Limitations

First, the scope of the study was limited, as the study period data was from 2010 to 2015 with death data until 2019, noting that it includes the total population who used the air ambulance service. However, the value of the study was to highlight how linked data can be used to explore aeromedical patient journeys and evaluate service quality, which aeromedical-only findings are unable to achieve. Changes may well have occurred in the aeromedical service since the study period: future linked data studies will be able to compare changes in service responsiveness over the intervening period. Secondly, there is considerable heterogeneity among aeromedical service processes which challenges the generalizability of these results [37]. However, describing referral pathways, the patients' journeys and assessing the patient and service outcomes has value across all processes. Thirdly, the process of clinical coding has been fraught with variability and subjectivity [38]. Data collected did not include chart findings from patient exams, surgical or lab findings. However, errors were minimized with coding standards and routine auditing among data custodians and the use of data linkage [39]. Finally, there are inherent limitation in retrospective cohort studies. However, the limitations were improved by utilizing STROBE [27] (Strengthening The Reporting of Observational studies in Epidemiology) guidelines improve the quality and transparency of reporting of the study (Appendix 4).

Conclusion

Linked data was used to explore aeromedical patients' journeys and examine referral pathway outcomes. The majority of patients originated from rural locations and entered via the ED at the receiving facilities; suggesting access limitations of diagnostic imaging in rural hospitals. The referral system is functioning efficiently with major complex patients less likely to have longer request-to-activation time intervals than minor complex, small number of patient discharged from receiving ED, small numbers of referrals to tertiary hospitals receiving an appendicitis diagnosis, and no deaths relating to appendectomy. Four recommendations include: use linked data studies to compare patients' journeys and referral pathway variations over time. Second, use linked data studies to explore other high frequency emergency general surgery procedures through the patients' journey perspective. Third, use linked data studies to explore the reasons for ED discharge after aeromedical retrieval to further improve efficient use of limited resources. Forth, further exploration of the rural clinicians' perspectives in requesting aeromedical retrieval for suspected appendicitis to help identify their strengths and barriers in the regional-level emergency care system.

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CRediT authorship contribution statement

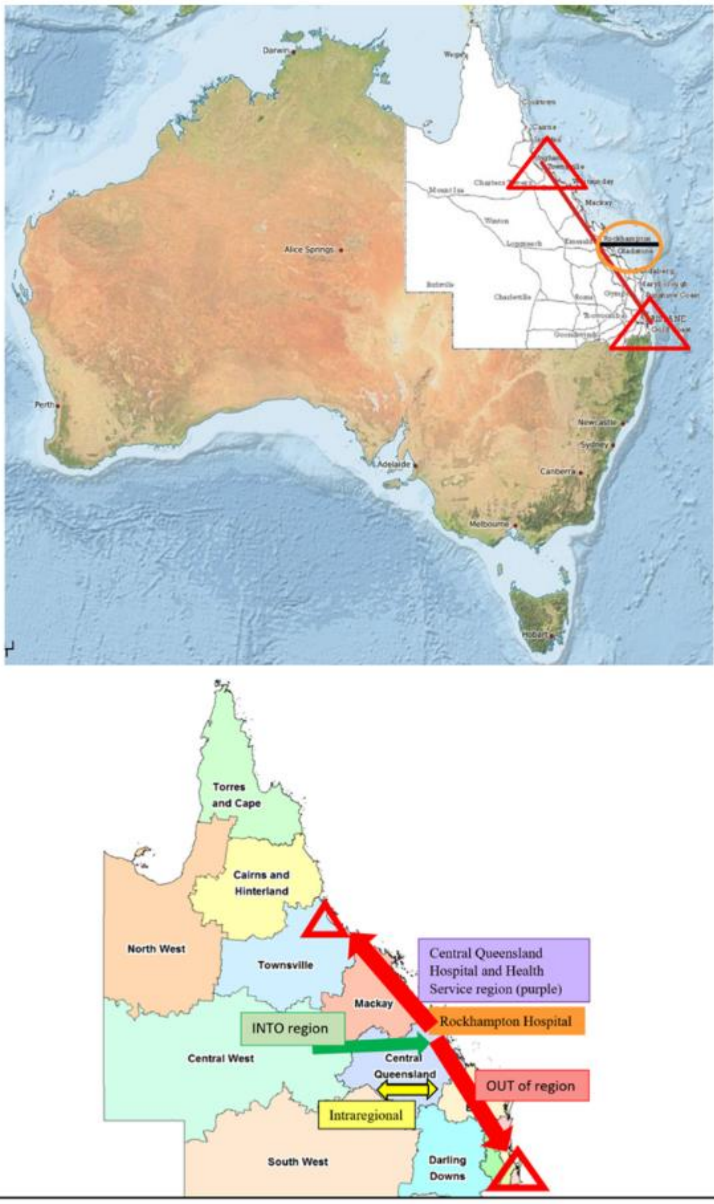
Kristin H. Edwards was the main contributor and lead author responsible for the ideas, development of the study and writing of the paper, and will contribute, as part of her PhD candidature and thesis. **Mark Edwards**: Writing – review & editing. **Sankalp Khanna:** Supervision, Writing – review & editing. **Richard Franklin**: Supervision, Writing – review & editing. **Rhondda Jones**: Supervision, Writing – review & editing. **Petra Kuhnert**: Supervision, Writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

Appendix 1

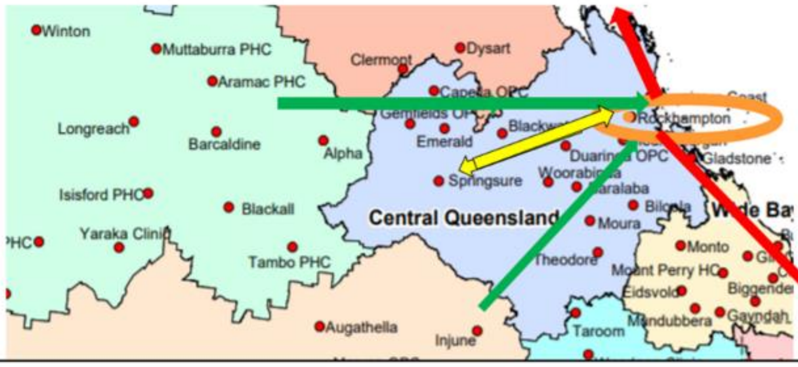
See Appendix 1, Appendix 2.



Legend: (Top image) Whitened outline: State of Queensland, Black underline: town of Rockhampton, Red line: flight path to tertiary facilities: Townsville to the north, Brisbane to the south (author approximated), and Red triangles: tertiary facilities, Orange circle: regional hospital. (Bottom image) Referral pathways Red arrows (OUT of region), Green arrows (INTO region), and Yellow arrows (Intraregional).

Source credit: (top image) http:www.eAtlas.org.au, (bottom image) http:www.qld.health.gov.au

Appendix 1. Map of study region.



Legend: Purple area: Central Queensland Hospital and Health Service region, Orange circles: regional hospital, Red dots: rural clinics and hospitals, Green arrows (INTO region), Yellow arrows (Intraregional).

Source credit: http:www.qld.health.gov.au

Appendix 2. Map of Central Queensland Hospital and Health Service region.

Appendix 3. Missing values from appendectomy subgroups

Variable	Appendectomy outcomes	
	Minor complexity n = 108	Major complexity n = 43
Request-to-activation interval time (hours) n(%)	11(10)	6(14)
SendingFacility LOS(hours) n(%)	7(6)	2(5)

Appendix 4. STROBE Statement - checklist of items that should be included in reports of observational studies [27]

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1–2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2–4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4–5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4–5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5–7
		Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls	
		Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7,8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7,8
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6–8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	8
		(*c*) Explain how missing data were addressed	8
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed	8
		Case-control study—If applicable, explain how matching of cases and controls was addressed	
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8,10–12
		(b) Give reasons for non-participation at each stage	10–12
		(c) Consider use of a flow diagram	11.14
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	12–14

		(b) Indicate number of participants with missing data for each variable of interest	25
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NA
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	12–14
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	NA
		Cross-sectional study—Report numbers of outcome events or summary measures	NA
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95 % confidence interval). Make clear which confounders were adjusted for and why they were included	NA
		(*b*) Report category boundaries when continuous variables were categorized	8
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	16–18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Title page

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6.2 Chapter summary

Chapter 6 addresses aim 3 of this thesis (to explore aeromedical patients' journeys in Central Queensland using linked data), comprising a quantitative study exploring aeromedical patients with suspected appendicitis and acute abdominal pain. Appendicitis was the most common sending illness in two of the three regional referral pathways, 'Intraregional' and 'INTO region'. Patients' journeys refers to the integrated, continuum of care that spans multiple settings; prehospital and hospital based pre-flight, aeromedical transport, receiving ED, hospital and disposition. Referral progression pathways describe hospital capability levels (rural-capability, regional-capability, and tertiary-capability) and are used to measure the occurrence of secondary overtriage (i.e., bypassing regional capability-level hospitals and transferring to tertiary facilities). By measuring the time intervals between 'request for service' and 'serviced activation', one can examine the responsiveness of the service, and determine whether the longest request-to-activation intervals are associated only with complexity of the appendectomy or are also associated with overtriage.

6.3 Salient points

- Males had significantly more major complex appendectomies than females.
- Aspects of an efficient aeromedical referral system were identified by three outcomes:
    1. Major complexity appendectomy patients were less likely to have longer wait times than minor complexity, therefore the correct identification of sicker, more urgent patients is crucial
    2. Few (5.6%) patients discharged from receiving ED, validating the need for the majority of transfer flights
    3. Very few (3.8%) appendicitis patients sent to tertiary hospitals, indicating the correct matching of patient need to hospital service level.
- Appendectomy with major complexity had significantly longer hospital stays (4.2 days) compared to minor complexity (2 days).

- The majority (83.3%) of all rural origin retrievals entered the receiving facility via the ED, rather than direct admission to hospital for surgery, suggesting access limitations of diagnostic imaging in rural hospitals.

Chapter 7. Results of qualitative interviews: Requesting air ambulance transport of patients with suspected appendicitis: The decision-making process through the eyes of the rural clinician

Overview of this chapter

To give an overview of this chapter, it is important to briefly review the last two chapters. Chapter 5 identified suspected appendicitis as the most common illness from sending hospitals in two of the three referral pathways in Central Queensland. Chapter 6 further explored suspected appendicitis and acute abdominal pain in the Central Queensland region. This chapter explores rural clinicians' self-reported knowledge, skills, and attitudes in the decision-making process for requesting aeromedical retrieval of patients with suspected appendicitis. Understanding the non-technical 'human factors' of the decision-making process is important, as this can impact patient safety and service effectiveness. Increased awareness of rural service limitation may improve communication between the sending and receiving clinicians and thereby improve timely patient care transfers. Chapter 7 addresses aim 4 of the thesis and presents the results of in-person clinician interviews synthesised in a narrative process.

- aim 4: To describe rural clinicians' perceptions of the supports and barriers they experience as they request aeromedical retrieval for patients with suspected appendicitis in Central Queensland.

Figure A summarises the main aims and outputs from the thesis and indicates the position of this chapter within the thesis.

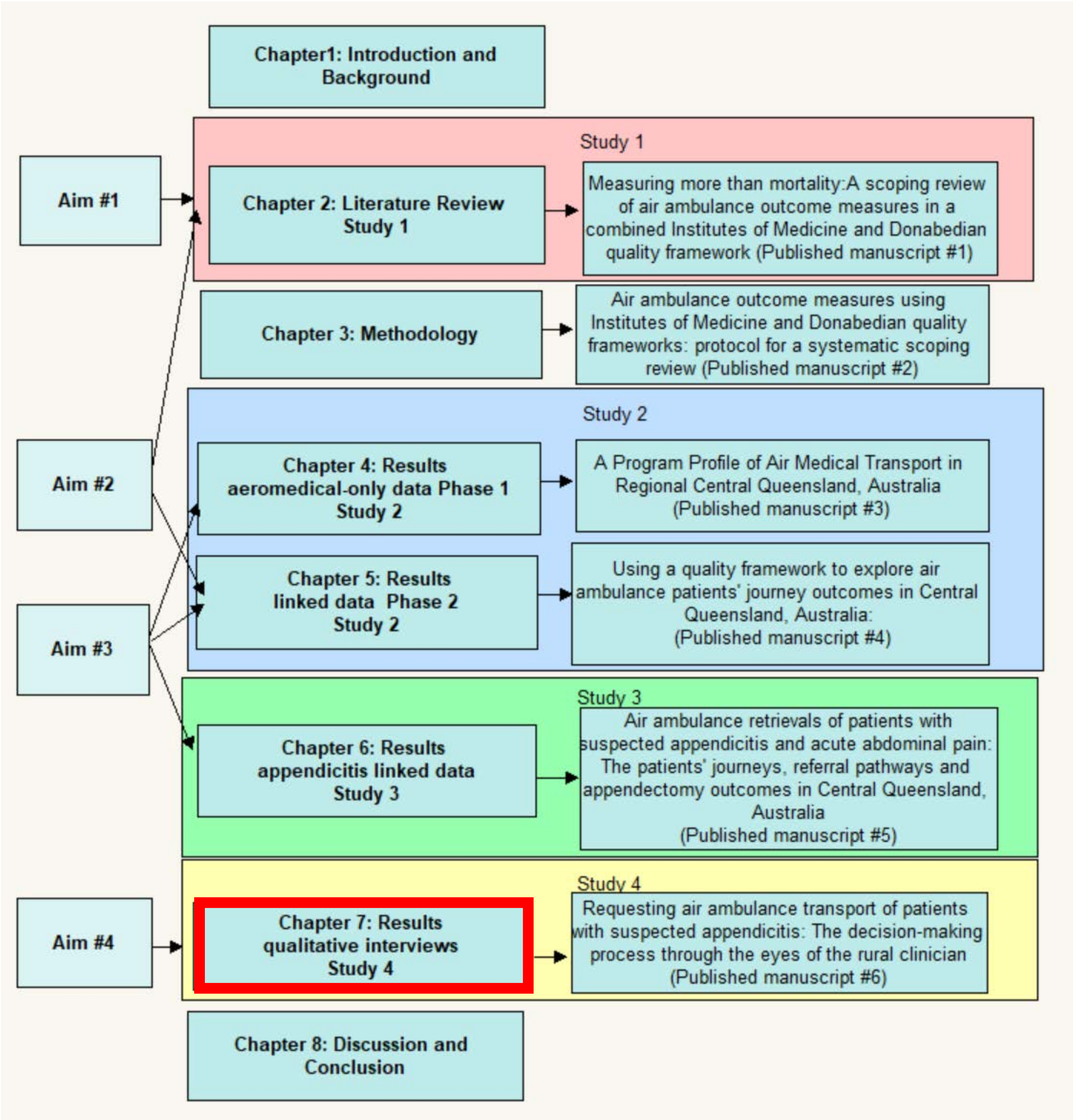

Figure A. Conceptual model of the thesis aims and outputs

Study aims 1-4 are in boxes on the left and the six publications are in the boxes on the far right. Study 1 is displayed in a red box, Study 2 in a blue box, Study 3 in a green box, Study 4 is in a yellow box, and a red rectangle outlines the chapter.

7.1 Manuscript

This chapter contains the following manuscript that has been published in a peer-reviewed journal, relevant to aeromedical retrieval, and is inserted as a published .pdf in the format required by the Australian Journal of Rural Health:

This chapter comprises a published manuscript. It is inserted as published. The citation is:

Edwards, K.H., Franklin, R.C., Stewart, R.A., Edwards, M.T. (2022). Requesting air ambulance transport of patients with suspected appendicitis: The decision-making process through the eyes of the rural clinician. *Australian Journal of Rural Health, 1-10.* https://doi.org/10.1111/ajr.12956.

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ORIGINAL RESEARCH

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Requesting air ambulance transport of patients with suspected appendicitis: The decision-making process through the eyes of the rural clinician

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Abstract

Objective: The primary aim is to explore rural clinicians' self-reported knowledge, skills and attitudes in the decision-making process for requesting aeromedical retrieval of patients with suspected appendicitis. A secondary aim is to understand the supports and barriers of rural clinicians experience in this clinical scenario.

Setting: Clinician interviews conducted face-to-face in three rural hospitals in Central Queensland.

Participants: Rural doctors and nurses.

Design: A five-part qualitative content analysis.

Results: The majority of 44 participants identified the strong and effective teamwork. The decision to request aeromedical retrieval was a shared, joint process and identified a supportive collegial culture which supported the asking of questions and not expecting to have all the answers. Perceived barriers were lack of receiving clinicians understanding of transfer agreements, and data connectivity. Clinician pessimism was identified for perceived patient outcomes.

Discussion: Effective teamwork can nurture trust and collaboration across multiple health service roles. High job satisfaction may counter the physical isolation in some rural environments. Fragmentation of care is the unintended consequence of interhospital transfer and may impact rural clinicians' perception of patients' outcomes and hinder receiving clinicians' understanding of rural service limitations.

Conclusion: Future work in the area of linked electronic medical records could remove a barrier for rural clinicians and improve their reflective practice by challenging their perception of definitive patient outcomes. Increased awareness by receiving clinicians of the limitation of rural services, may minimize communication barriers and thereby, improve timely patient care transfers.

KEYWORDS

communication, emergency, health informatics, health outcomes research, rural health service delivery

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Appendix:

Appendix 7.1. *Clinician interview questions in five domains*

Knowledge, Skills and Attitudes Questions for Participants

Domain 1: Roles of clinician in the decision process of aeromedical transport

1. What is your role in the emergency department?
   1.2 How long have you been in this role?
2. What is your role when a patient is suspected of appendicitis?
3. Who decides if a patient requires specialized care for their suspected appendicitis to which requires aeromedical transport?

Domain 2: Perceptions on how prepared clinicians' feel in their role to request aeromedical transport

4. What training have you had for the care of patients with suspected appendicitis?
5. What training have you in the process to request aeromedical retrieval?
6. How frequent do patients require aeromedical transport for suspected appendicitis?

Domain 3: Perceptions of urgency, uncertainty of illness and alternative supports for diagnosis

7. In those patients that you have suspected appendicitis, how urgent was their need for specialized care and aeromedical transport?
8. How certain did you feel in your clinical observations of urgency and/ or differential diagnosis?
9. What alternative supports are available to you, to confirm or rule-out diagnosis?

Domain 4: Perceived challenges and/or support in requesting aeromedical retrieval

10. Do you feel that there are challenges in this process from differential diagnosis to request of aeromedical transport?
11. What do you feel are your supports during this same process?

Domain 5: Attitudes of what might overcome any perceived deficiencies in preparing best care for patients with suspected appendicitis

12. Are there methods or materials that may prepare you in your role with these patients in requesting aeromedical retrieval?
13. Are you optimistic that these measures will come to pass?

7.2 Chapter summary

Chapter 7 addresses aim 4 of the thesis and describes rural clinicians' perceptions of the supports and barriers they experience as they request aeromedical retrieval for patients with suspected appendicitis in Central Queensland. The study adds increases understanding of rural clinicians' knowledge, skills, and attitudes of the decision-making process in this illness group undergoing aeromedical retrieval. Chapter 7 completes my investigation of aeromedical retrieval in Central Queensland.

7.3 Salient points

- Forty-four in-person clinician interviews were conducted in three rural hospitals in Central Queensland Hospital and Health Service region.
- The professional roles interviewed included enrolled nurses, registered nurses, senior medical officers, medical and nurse practioner students, medical registrars, and directors of nursing.
- A five-phase narrative analysis found a meta-theme concept of ‘teamwork in rural locations’ and three sub-theme concepts: ‘trust and collaboration’, decision-making under uncertainty’ and ‘communication is key’. For each sub-theme there were three indicators: ‘assessment supports’, ‘freedom to ask’, ‘mutual respect’, ‘preparation’, ‘urgency’, alternative supports’, ‘advocating for patients’, ‘speaking-up’ and ‘breakdown’.
- An environment with high collaboration and trust seemed to counter the isolation identified by rural nurses.
- Some clinicians were pessimistic regarding their patients’ full recovery due to distance from higher levels of care and the potential long transfer time.
- Several clinicians acknowledged their lack of certainty diagnosing appendicitis without diagnostic modalities like CT or ultrasound.
- Clinicians felt supported when asking questions in a shared decision-making environment, verbalising their professional knowledge, and advocating for their patients, thereby increasing patient safety and quality care delivery.
- Clinicians identified the lack of useable, accessible, and connected EMR as a barrier for reflective practice.

- Future advances in health data linkage could encourage rural clinicians to challenge their own and others' negative attitudes about rural patient outcomes.

Chapter 8. Discussion and conclusions

Overview of this chapter

This chapter, presented in three sections, aims to integrate and discuss the findings from the four previous studies and situate them within the broader literature and public health implications. The first section presents a brief summary of the six publications. The second section is a discussion of the public health implications specific to healthcare practice, education, leadership, policy, and research. The final section is an outline of knowledge translation from the Knowledge-to-Action Process Framework[1] to plan the dissemination and implementation strategies. Figure A summarises the main aims and outputs from the thesis and indicates the position of this chapter within the thesis.

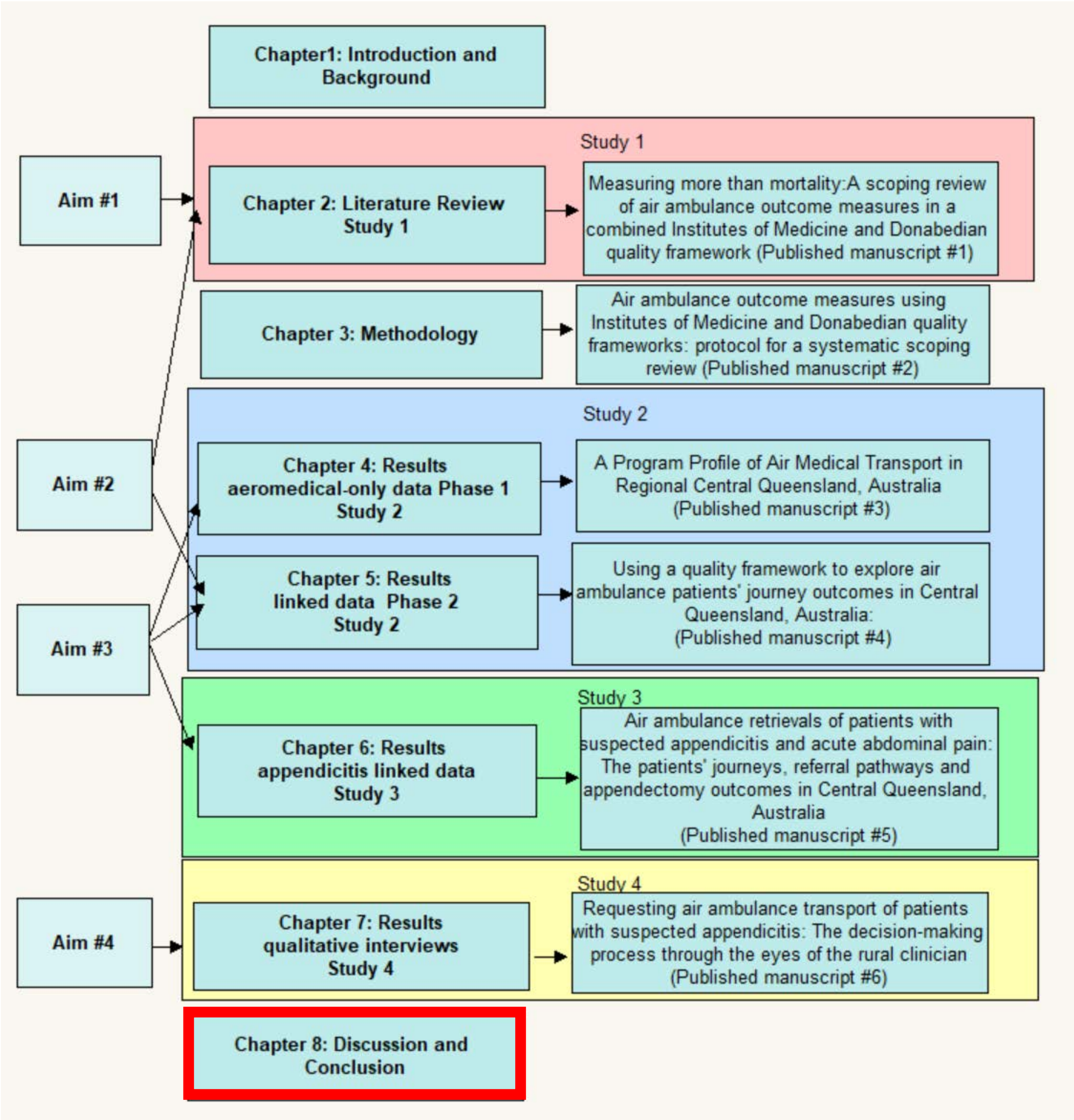

Figure A. Conceptual model of the thesis aims and outputs
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8.1 Thesis Outcomes

This research fills the following gaps in knowledge in the area of aeromedical retrieval service:

1. Aeromedical patient and service outcomes in Central Queensland Hospital and Health Service (CQHHS),
2. Creation and use of an aeromedical quality framework based on the range and nature of outcome measures used in the literature,
3. Identification of rural clinicians' perceived supports and barriers as they request aeromedical retrieval for patients with suspected appendicitis.

The overall objective of this study was to explore the performance of a regional aeromedical system to inform the development of a performance evaluation framework for aeromedical services. This thesis posed four aims, addressed by one or more studies, which created the foundation of the research. Recommendations in healthcare practice, education, leadership, and policy are presented in this chapter, based on the findings from the thesis.

The four aims were:

1. To document the range and nature of aeromedical outcome measures in the literature.
2. To use the results of aim 1 to develop an aeromedical quality framework and use it for reporting existing aeromedical patient and service outcomes.
3. To explore the aeromedical patients' journeys in Central Queensland using linked data.
4. To describe rural clinicians' perceptions of the supports and barriers they experience as they request aeromedical retrieval for patients with suspected appendicitis in Central Queensland.

Each of the four aims will be discussed in sections 8.2, 8.3, 8.4, and 8.5, which will summarise the studies, describe their key findings, integrate and reflect on their implications for aeromedical health service provision.

Finally, this research was used to create and develop an aeromedical quality framework to report on aeromedical service provision and explore areas for improvement based on the range and nature of aeromedical outcome measures (Study 1). This thesis explored the aeromedical framework's feasibility and function in guiding future conversations regarding system performance and future planning (Chapters 5 and 6). The utility of the aeromedical framework will be explored in section 8.3. The final section of this chapter will integrate[4,5] how the three thesis questions have been answered and how each of the four aims have been addressed.

8.2 Thesis aim 1

A systematic scoping literature review was conducted to address aim 1. The scoping review examined the range and nature of research activity[6], as opposed to a systematic review that assumes a narrow, clearly defined question[7]. The complete results of the search terms and scoping review were presented in publication 1[8].

Before this study began, the range and nature of aeromedical outcomes in the literature were uncatalogued. According to the Institute of Medicine (IOM), failure to identify the range, variation, or gaps in outcome measures hinders the ability to recognize service disparities[9] (p.382). Therefore, ongoing review of patient and service outcomes are important for the service to meet the future needs of the community and to minimise service provision inequity. Study 1 has added to the knowledge presented in previous literature by identifying the range, variation, and gaps in published aeromedical outcome measures.

There are three reasons for gaps when cataloguing air ambulance outcome measures. Firstly, there is considerable heterogeneity among aeromedical services. These differences include geographical base locations (e.g., remote vs. urban) and available aircraft (only rotor-wing (RW) vs. both RW and fixed-wing) (discussed in section 1.3.5). Flight time for instance is a non-specific outcome measure which does not adequately capture these differences. The use of this non-specific measure makes comparing service quality difficult; for example, flight time may vary depending on aircraft type and distance travelled. Urban helicopter flight times (short distances) cannot be meaningfully compared to rural fixed-wing flight time (long distances). To address this, the methods section of study 2 and 3 included the type of aircraft and the distance travelled between rural and tertiary hospitals when calculating flight time.

Secondly, aeromedical service outcomes are connected to the healthcare services delivered before and after flight (discussed in section 1.2). Therefore, when suboptimal care is delivered before or after any aeromedical intervention occurs, it may impact the patient condition and alter the patient outcome when in the direct care of air ambulance crews.

Thirdly, the high acuity and complex comorbidities of patients may relate more to the patient outcomes than the quality of aeromedical services (discussed in chapter 1 section 1.3.4). For example, a highly acute patient may have a risk of imminent mortality that is unrelated to the quality of care.

These three examples can be set within the theories of Systems[2] and Complex Adaptive Systems[3]. In that they have numerous interconnected elements, they are diverse, varied and adaptive in that the processes have the capacity to change based on experience[2] (discussed in chapter 3 section 3.7). Therefore, this knowledge linking data before and after aeromedical flight will help contextualise service and patient outcome variations, interconnectedness, and corresponding adaptations in CQHHS.

Overall, outcome measures and independent variables in the literature evaluating aeromedical care are mainly centred on the aeromedical event. Aspects of the pre-flight period focused primarily on the patients' physiological status and the implied necessity of aeromedical transport. For example, none of the studies described emergency general surgery

(EGS) transfers, none described the interhospital transfer (IHT) setting before and after flight as included in the journey, and none described a regional referral structure (Chapter 2, table 2.1, section 2.1). By contrast, the review of outcome measures and independent variables in this thesis included the aeromedical event as well as the events before and after the IHT (e.g., sending/receiving hospital capability level, length of stay (LOS), and patient disposition).

There was one independent variable that was included in the scoping review findings, but was not included in study 2 and 3, because the data item was not requested from Queensland Health. The data item was 'scene interventions' (e.g., patient intubation at the scene). In contrast, there were three outcome measures *not* found in the scoping review results and also were *not* included in study 2 and 3 because they were not requested from Queensland Health: patient pain scores, delays due to waiting for ground transport, and in-flight interventions. Therefore, I recommend future studies include these four indicators not covered in this thesis: scene interventions, patient pain scores, delays due to waiting for ground transport, and in-flight interventions. I also recommend that aeromedical services regularly collect these indicators regularly for review. As use of these indicators will help providers to produce more accurate evidence for decisions of health resource allocations across the health system.

The overall study characteristics of the literature review found that 65% of all the selected studies originated from America. This may be due to the number of aeromedical services available to the large population. However, there were only four studies (22% of the overall total) from Europe, including Scandinavia, and only one study each (5% of the overall total) from Australia, Canada, and Japan. The majority of studies focused on trauma (60% of the overall total), with only 25% on stroke. This is an issue, as our study is set in Australia with high frequency of cardiac-related aeromedical retrievals. The high proportion of studies focused on trauma, may be due to the funding available for aeromedical-trauma-related research from automotive industries[10].

8.3 Thesis aim 2

Aim 2 required the results of aim 1. Prior to the work in this thesis, there was no aeromedical quality framework to aid aeromedical retrieval service providers in conceptualising quality and focusing improvement efforts. This research engaged multiple methods to explore the literature, create a framework, and explore its feasibility in linked data.

Two of the challenges in healthcare is defining and measuring the abstract construct of quality. Sustainability of healthcare services depends on successfully defining quality[11-13] (discussed in chapter 1, section 1.2). In general, aeromedical services maintain a list of key performance indictors from medicine, aviation, and public health, yet a quality framework that is specific to air ambulances has been lacking until now. The aeromedical quality framework's structure and function design fills previous gaps in reporting aeromedical service quality in three aspects: data utilisation should be *manageable, meaningful,* and *measurable*[14]. These three terms will be used throughout aims 2 and 3 to describe key findings and reflect on their implications for aeromedical health service provision.

The aeromedical quality framework is *manageable*[14]. It provides a balanced visual dashboard of service provision (displayed and described in publication 1[8]), and will allow users to categorise considerable amounts of outcome indicators and organise them visually to see where there are gaps (as displayed in study 1, 2, 3 results). It is flexible to adapt to the variation found in Central Queensland (as discussed in chapter 5) and the general lack of aeromedical standardisation among service providers found in the literature[15-18]. For example, if the providers did not have outcome measures which would fit in the IOM rows and

Donabedian columns, there would be nothing represented; it would be empty. Therefore, the aeromedical quality framework displays gaps in areas of service provision or data collection deficiency which could hinder the ability to recognise service disparities[9]. Prior to this study, these gaps were unknown or unreported. However, with the knowledge of these gaps, future patient outcome and service research can be expanded by including these outcome measures and independent variables in future data linkage analysis.

The aeromedical quality framework is *meaningful*[14] to service providers and planners. The framework provides a basis to monitor if service delivery is meeting their intended key performance indicators. The creation and implementation of the aeromedical quality framework has the potential to impact healthcare practice and public reporting. However, further feasibility assessment of the framework is necessary to test the performance criteria in air ambulance services outside of Queensland. To do this, the framework needs introduction to aeromedical providers, payers, and planners in settings such as aeromedical conferences and then to be used. This knowledge translation strategy is discussed further in section 8.9.

8.4 Thesis aim 3.

The third aim explored aeromedical patients' journeys in Central Queensland using linked data. According to Dr. Avedis Donabedian, assessing healthcare quality was bound by the strengths and limits of clinical science, as outcomes may relate the antecedent processes of care[19] (p. 1148). Therefore, the interconnected processes of care require exploration. Prior to the beginning of this thesis, aeromedical patient data was not linked to health care processes before or after flight, including mortality data.

Aeromedical retrieval is part of the continuum of care services in the emergency system that includes emergency and ambulance dispatch, hospital-based emergency, trauma care, and inpatient service[20] (p. 81). In the thesis, aeromedical patients' journeys are defined as the integrated, continuum of care that spans multiple settings. Emergency medical services, including aeromedical retrieval, are part of the Australian public health system. In this design, improved patient and service outcomes benefit the whole, so an Australian strategic health service plan must identify and evaluate performance indicators along the continuum of care[21]. This requires data to be linked and analysed. Similarly, American health service data are also largely not linked, as services are generally privately owned and operated with few linkage opportunities[22]. In this American health service context, performing data linkage analysis has many challenges[23,24].

The value of data from aeromedical patients' journeys lies in its use[25]. Data linkage provides the ability to construct the aeromedical patients' journeys from sending locations through to receiving locations and discharge. Prior to this study, outcome details related to the patient journey, such as LOS, flight time intervals, admission/disposition pathways, multiple flights per person (flights from rural-level care to regional-level care to tertiary), and death, were widely unknown[26].

The greatest value of data linkage undertaken for this thesis was the emergent picture of three distinct referral pathways for managing patient needs in CQHHS. The referral pathways had their own pattern of care: toward tertiary-level care, toward regional-level care and either back from tertiary-level care or toward regional-level care from outside of CQHHS. For example, aeromedical flights in CQHHS toward tertiary care will most frequently require fixed-wing aircraft and are more likely to be cardiac or neurologic-related illness/injuries (discussed in more detail in chapter 5 and chapter 6). Further explorations into aeromedical outcomes need to take these referral pathways into consideration, especially when trying to measure the outcomes of the service. Therefore, further studies of referral pathway analysis using state-wide linked aeromedical patient and service data are needed (listed in the recommendations section 8.8).

The results collected from the state-wide referral pathway analysis, will help create a service capability model based on scope of unique patient and community needs into the future. This will be accomplished by identifying aeromedical patient's types of illness and injuries, on flights leaving the sending hospital and health region and receiving their healthcare needs outside of the region. This may indicate healthcare services not available to patients at their sending location. Analysis of referral pathways from each of the sixteen regions in the State of Queensland can also provide comparisons between regions and promote ongoing improvements. Additionally, it is noted that these referral pathways are likely to occur in other hospital and health regions within the State of Queensland. This is a novel finding, and it is unclear the frequency of aeromedical retrieval in regions with tertiary hospitals within their borders, or in regions without regional-level hospitals in their borders.

This program of work has provided linked data outcomes that provides pre-hospital and hospital-based providers with knowledge of patient and service outcomes[20]. According to Newgard, et al.[23], "the capture and processing of such standardized emergency medical system information provide an opportunity to link out-of-hospital care to hospital-based care and better utilize important acute care information across transitions in care"[23]. Indeed, linking and analysis of patient-level data, which has been achieved in this thesis, has been the continued aim for emergency care systems by the Institutes of Medicine in America for over a decade[20] (p.98).

The data linkage analysis process is *manageable*[14]. Big data is not as big as it seems initially[26]. For example, the initial seven data files (Retrieval Services Queensland (RSQ), Royal Flying Doctor Service (RFDS), LifeFlight Retrieval Medicine (LRM), Queensland Neonatal Emergency Transport Systems (QNETS), Queensland Hospital Admitted Patient Data Collection (QHAPDC), Emergency Department Information Systems (EDIS) and death) was comprised of 1,112,084 patient records and over five million data points. However, with data cleaning and sample selection, the working file size is reduced to 13,977 records (discussed in chapter 3 section 3.4.2), making the size of the linked data *manageable*.

The data linkage findings are *meaningful*[14] as they may considered important by both the clients and providers of health services. In chapter 5, the picture that emerges from the analysis is one of a complex referral system; three distinct pathways manage different patient needs with variable degrees of urgency, yet all are intrinsic to the regional system in Central Queensland. These findings support the theories of Systems[2] and Complex Adaptive Systems[3] which allows for heterogeneous agents and emergent behavior[3]. This study helped establish data links between patient aeromedical flights, their associated ED or hospital records, and the death registry, and helped to identify analysis shortcomings. For example, analysis that relied exclusively on overall regional outcomes and ignored the differences between the referral pathway outcomes in each region.

In another example of Complex Adaptive Systems Theory[3] in referral pathways, the predominant pathway transported 55.6% of patients from CQHHS toward tertiary-level care in the ‘OUT of region’ pathway, 750+ kilometres outside of the region (discussed in chapter 5). However, 68.6% of these were less urgent, P4 and P5 tasks, and 95.8% were transported on fixed wing aircraft. In stark contrast, patients referred in the Intraregional pathway were 31.8% lower urgency P4 & P5 tasks, and 28.3% on rotor wing aircraft. These examples support the analysis of state-wide data linkage through the lens of regional referral pathways, as the findings are nuanced and more informative for future planning improvements. In the final example (discussed in chapter 5), the ‘OUT of region’ pathway had predominant pathology (21.6%) at the sending hospital relating to coronary heart disease (CHD). These findings are higher than the 6.9% CHD National Burden of Disease total in 2015[28].

While the regional referral network was designed to reduce duplication of health resources, there must be a balance between community burden and benefit to the health service[18]. Currently, there are efforts in Australia and CQHHS to reduce CHD patients' risk factors, improve their treatment, and increase secondary prevention[28]. However, these efforts are hindered by the lack of skilled clinicians in regional and rural communities (discussed in chapter 1, section 1.9.2). The findings in chapter 5 suggest the CQHHS region has higher cardiovascular disease admissions than the National rates, which reflects disparities in cardiovascular health for rural communities[28]. Improved future accessibility to acute cardiac services, recovery, and rehabilitation may include transporting medical teams directly to rural clinics. Further research is recommended to better understand the referral pathway patterns of condition-specific transfers to help plan community needs and improve service efficiencies. These include coronary heart disease, stroke, and high-frequency emergency general surgery procedures, such as partial colectomy, small-bowel resection, cholecystectomy, operative management of peptic ulcer disease, lysis of peritoneal adhesions, and laparotomy[29].

The data linkage analysis findings were *measurable*[14]. The previous limitations of siloed aeromedical data in regional (Chapter 4) and state-wide[30] analysis has been strengthened by linked data analysis, as evidenced by forty variables of interest categorised in nine main themes created by the linkage process. These nine main themes are: mortality, referral pathway, asset/ team type, access to definitive interventions, accessibility and frequency of service, responsiveness of service, patient admission to facility, patient disposition from facility, perceived urgency. This is compared to only sixteen variables, in six themes in siloed aeromedical, as described in chapter 5, section 5.2, and Additional analysis Table 5. Of the forty variables of interest explored using data linkage, twenty-six were not previously available in aeromedical-only analysis. This level of measurement and feedback are key to quality improvement, as “data can be used to identify areas where services are doing well and areas where improvement is required”[31].

At the start of this study, the RSQ, LRM, RFDS, and Queensland Health Master Linkage File (data that is collected from the emergency department, hospital inpatient and death) were independent and not linked to one another[26]. Since that time, authors Andrews et al.[32], have published a process mining analysis of RSQ and ground ambulance data[32]. Methods chosen for this thesis were implemented prior to the publication of Andrews et al. However, two substantial distinctions should be highlighted between their study and this thesis. Firstly, Andrews et al. focused their study on road-side trauma to definitive care, excluding RFDS interhospital transfer data as evidenced in their event time inventory[32]. In my thesis, RFDS provided a sizable volume of data, accounting for 46% of the total available aeromedical data files (Chapter 3, table 3.3, section 3.4.1). Secondly, it is not clear that Andrews et al. explored the interaction between CCRIS, QNETS, and LRM records. This thesis discovered that one CCRIS record is often linked to one LRM record for one patient flight, meaning multiple records may be related to one, single flight episode. These two distinctions were described in detail in chapter 3, section 3.4.5, and visualised in figure 3.5 to validate my chosen methods and their importance to inform clinical and process discovery.

Two similarities exist between this thesis and Andrews et al[32]. Both studies found missing flight timestamps. For example, in this thesis, the event time ‘depart receiving hospital’ had 84% missing values. However, linking RFDS data resolved this problem. This highlights the need to have consistent definitions between the different data sources to ensure that critical linkage keys are collected. Secondly, both studies extracted data from an old RSQ data management system[33]. The new system, called BROLGA, commenced in late 2017[33], post-dating data collection in both studies. To the best of my knowledge, this thesis was the first data linkage study that included and identified RFDS and LRM service providers, described time gaps in the linkage (Chapter 3, section 3.4.4, figures 3.3 and 3.4 and section 3.4.7, figure 3.6), and identified unique timestamp event differences among providers (visualised in chapter 3, section 3.4.4, table 3.6). Further timestamp event differences and time gap findings will be discussed in section 8.5. Utilising data linkage has removed the limitations of utilising aeromedical-only data and has contributed to the findings of aeromedical patient and service outcomes.

Finally, the *meaningfulness* of linked data analysis used in study 2 and 3 was highlighted in the use of back-transfers from higher level facilities to lower level. This finding supports the use of pre-flight holding areas, which are also known as transit lounges, for patients ready for room discharge but not ready to be transported from the hospital. The Internal Medicine Society of Australia and New Zealand (IMSANZ) made attempts to increase patient flow in 2006[34]. However, this plan did not include processes for patient discharge *from* an inpatient bed, which is the scenario of most back-transfer IHT's. Fortunately, progress in patient flow has been made since 2006. A tertiary hospital, the Princess Alexandra Hospital in Brisbane, currently uses a Transit Care Hub (TCH) intended to improve patient flow for patients waiting for interhospital transfers[35]. The TCH provides waiting areas for the period after a patient discharge from the wards, and transfers patients from EDs when there is a wait for resources or services (e.g., scripts, final medication review, final bloods, final radiology scans)[35]. To date, the model is efficient[35] and has potential to assist the timely flow of aeromedical IHT patients. Therefore, the recommendation is for further research using TCH and aeromedical retrieval patients.

Future aeromedical linkage research will benefit from including Queensland Ambulance Service (QAS) data, and current RSQ information system data. The QAS service is connected to the emergency care system, which will help to give a more complete picture of the aeromedical patients' journeys. Analysis should include aeromedical paramedic clinical data and QAS ground transportation time intervals, such as patient and aeromedical team transport from airport to/from hospital. Publication 1[8] identified the lack of ground transport event time in the literature (Chapter 2), called the optimal coordination of resources. My recommendation is for future regional referral pathway analysis to include QAS ground transport connections (listed in the recommendations section 8.8). Additionally, future analysis should include the current RSQ data information systems, BROLGA[33] and the Minimum Data Set (MDS)[33], and utilise data items not previously available (Table 8.1). These nine data items will expand current knowledge, with details in the transfer process, patient severity, and the patients' journeys.

Table 8.1. BROLGA and MDS (RSQ information systems) nine data items to include in future analysis

BROLGA and MDS-specific data items (RSQ data information systems):
1. Handover location (e.g., Tarmac or Hospital)
2. Patient Severity
3. Reason for call
4. QADDS score (i.e., QH patient deterioration scoring)
5. Clinical notes
6. Warnings (e.g., Covid precautions, bariatric patient needs, bed availability)
7. Telemedicine (within BROLGA's 'Situation' tab)
8. Behavioural Risk Assessment (within BROLGA's 'Requirements-Operations' tab)
9. Death in Care (dd/mm/yyyy hh:mm)

Variation in discrete air ambulance event times found in data linkage

Chapter 1 section 1.3.5 highlighted that there is no universally accepted list or standard definitions of aeromedical retrieval event times recorded by all aeromedical providers in Queensland. As a result, recorded timestamps of selected event timings may vary between different aeromedical services working on the same task. Understanding the event time variation is vital to correct event matching. There are three explanations for event time variation. Firstly, precision data entry is a challenge in austere environments such as retrieval medicine. Clinicians focus is on patient safety, not on precision data entry. Errors in these scenarios are common[7]. Timestamp errors found in studies 2 and 3 were reported in the methods chapter 3, section 3.4.2.

Secondly, data may be manually recorded with paper and pen in an aircrafts' high vibration environment and a scene's dark night or difficult weather conditions, challenging legibility and increasing the potential of incorrect data entry. Finally, interval time may be selected to place the aeromedical service in the best light, often called 'cherry-picking', selecting only the best or most desirable from a group[36]. For example, 'transport time' may begin at departure from the scene until the arrival at the receiving hospital, but neglect to include other transport interval times, such as the interval from base to the patient, from landing at scene to 'with patient', or from landing at the receiving hospital to unit bed and handover. Choosing the shortest transport interval might make the retrieval task appear quick, but it is not necessarily a true reflection of the complete transport time to definitive care. Compiling transport intervals into one grand measure, 'Comprehensive Patient Journey Time' (from activation-to-handover), is a more meaningful time interval, as discussed in publication 1[8]. This grand measure may help to overcome the lack of standardisation and enable service comparison in aeromedical time measures discussed in chapter 1, section 1.3.5.

Time gaps found in data linkage

Future data linkage analysis must be aware of gaps in collected timestamps for rigorous linkage results. The first time gap, Type 1, was identified between the RSQ data files Clinical Coordination and Retrieval Information Systems (CCRIS) and QNETS request times and the LRM and RFDS activation times (shown in chapter 3, section 3.4.4, figure 3.3). This gap may be explained by the tasking processes at the RSQ aeromedical coordinator centre. In general, lower acuity and more stable patients do not require immediate retrieval. Another factor affecting this time gap may be due to beds at receiving facility not immediately available for an incoming patient. Therefore, the gap between the request of service and activation of the crew may span a few hours or even days.

The second time gap, Type 2, was identified between requests for service and patient discharge time from hospital (shown in chapter 3, section 3.4.4, figure 3.4). This may be explained by the process in which clinicians communicate their intent to transfer a patient before actual discharge. The gap may be from an early request, or it may be a lower priority patient who does not require immediate transfer, therefore the request may get placed in a queue following more urgent requests.

The final gap, Type 3, occurs between the process of handover and the receiving hospital start time (shown in chapter 3, section 3.4.4, figure 3.6). Handover event time marks the end of one clinician's care responsibilities to the start of another. This period often includes changing over medical devices such as monitors, medication pumps, ventilators, or medication tubing/lines, and physically moving the patient from one gurney to another. However, in some circumstances, aeromedical handover may occur on the airport tarmac given to a ground ambulance crew[37]. The ground crew will then transport the patient to the hospital. Linked data in this study, does not specifically include time in a ground ambulance, resulting in a potential time gap. Time gap intervals may depend on hospital location in relation to its closest airport, as ground ambulance crews may transport patients significant distances to the nearest available runway. In the Queensland's capital city, the Brisbane Airport is approximately 15 kilometres from the Royal Brisbane and Women's Hospitals through congested urban roadways, whereas the Rockhampton Regional Airport is approximately 2 kilometres from the public hospital. Rockhampton Base Hospital began operations using a rooftop helicopter landing pad on 24 September, 2015, in an attempt to minimise the ground transport time gap, but even then a small gap between landing on helipad and handover may still occur. These gaps likely account for time waiting for rotors to cool, and/or crew walking to the hospital unit. Identifying these three types of time gaps will be helpful for future data linkage analysis in Central Queensland.

Transfer movement definitions

Studies 3 and 4 created two novel definitions of transfer movement patterns. Aeromedical referral progression pathways are a referral to change the patients' level of care, for instance: rural hospital-to-regional hospital, rural hospital-to-tertiary hospital, regional hospital-to-tertiary hospital, tertiary hospital-to-regional hospital, or regional hospital-to-rural hospital. Aeromedical regional referral pathways, on the other hand, are the referral of patients toward appropriate levels of care in reference to the hospital service region (e.g., 'Intraregional', 'INTO region', 'OUT of region'). Analysis of each of these pathway types provide novel awareness of patients' service utilisation needs[38]. This gives planners an opportunity to re-evaluate the needs of a community's service provision. Patients requiring IHT may be a reflection of mismatch in sending facility staffing levels or skill mix, medical speciality availability, bed availability, or diagnostic modalities and treatment services.

Increasing trends in both aeromedical referral progression and regional referral pathway types are the canary in the coal mine. Surging regional referral pathway patterns out of health service boundaries may indicate gaps in hospital and health service provision and/or delivery. Soaring referral progression pathway patterns from rural- to tertiary-level resources may indicate gaps in the regional-level service capability. Overall, access to healthcare for patients in rural communities who rely on aeromedical retrieval to transport them over great distances using limited resources with no guarantee of availability may not deliver equitable quality care. Therefore, this thesis recommends further research to establish pre-threshold alarms (i.e., upward utility trends that may indicate volume stress and put pressure on safe, appropriate, early intervention and transfers) in both regional referral pathways and referral progression pathways (discussed in publication 1[8]). This recommendation aligns with the Institutes of Medicine's guide: "to chart the direction for emergency care systems to be accountable for overall performance and the needs of patients of all ages within the system"[20] (p. 81).

An example of charting the direction for emergency care systems is found in study 2. This study found cardiac-related illness was the most common in sending ED ICD code myocardial infarct in the 'OUT of region' pathway (112 episodes, 21% of sending ED pathway total), and ICD codes for stroke at the receiving ED 'INTO region' pathways (53 episodes, 3% of the receiving ED pathway total). The results are consistent with the fact that cardiovascular disease carries the greatest burden of disease in Australia[28]. The results in Study 2 show the most common tasks were cardiac-related. This may reflect disparities in cardiovascular health for rural communities. Improved accessibility to acute cardiac service, recovery, and rehabilitation may include bringing medical teams directly to rural clinics in the future. Understanding the patterns of these condition-specific transfers will help plan community needs and improve service efficiencies.

Mortality

An aspect of constructing the aeromedical patient journeys involves patient deaths. The results of the scoping review found mortality of aeromedical patients has generally been measured along select time intervals at the receiving ED or direct hospital admission (e.g., mortality after admission or survival to ED discharge) (found in chapter 5). The aeromedical quality framework included mortality in four IOM quality domains within the Donabedian Patient Outcome column, but the near- and long-term risk of mortality after surviving an aeromedical retrieval has been understudied. Mortality focused on long-term, one-year mortality has been the focus of recent studies of cardiovascular diseases, due to disease frequency and enhanced treatment and prevention strategies, which have prolonged median survival time of treated cardiac-diseased patients[39-42]. Similarly, among the total burden of diseases groups in Australia, the most common are cancer and cardiovascular diseases[28,43]. Novel cardiovascular disease treatment techniques have inconsistent results in the short-term, yet are associated with value in 1-year follow-up[44]. Considering these findings, long-term survival analysis beyond 30 days has value[42], given Australia's high rates of cardiovascular diseases and the inconclusive results of long-term follow-up.

The mortality results in chapter 5, publication 4, found that short-term mortality (0-31 days) and 1-year mortality of aeromedical retrieval patients is high (25% for 0-31 day, and 44% >1 year of total mortality). The variation among regional referral pathways had small size differences between Intraregional and 'INTO region' pathways. This thesis recommends further research into near- and long-term mortality variation between pathways, illnesses, genders, and age groups. These subgroup recommendations are supported by the Australian Institute of Health and Welfare[45] (2018), due to different attitudes towards health and other risks, the way each group uses health services, and differences in health outcomes and wellbeing[45].

Number of Flights per Patient

The analysis of per-patient use of aeromedical services, to the best of my knowledge, has not been explored in prior publications (see chapter 5). While the majority of patients (79% of the total) used the service one time during the study period, the 2,289 patients which flew more than one flight are of particular interest. Previous theories of healthcare use has followed an 80/20 rule[46], meaning 80% of healthcare resources and costs are used by 20% of the population. This may appear to be the case with air ambulance resources, as well. However, in this study, there were 187 patients (8% of the multiple users) that are on the very top end of multiple aeromedical use (i.e., four or more flights during the study period). The recommendation is for further research into this subgroup, now that linked data analysis has joined them together, on why these multiple journeys may occur. Further exploration into multiple aeromedical use patients' illness, age, gender, sending facility, illness, and injury will help to target very specific interventions and reduce aeromedical utilisation.

In concluding aim 3, prior to the onset of these studies aeromedical patient and service outcomes in Central Queensland were unknown. Data was siloed and not linked to the sending and receiving facilities and the death registry. This body of work has filled this knowledge gap. The linked data methods connected the siloed data to create a comprehensive picture of patient and service outcomes. The findings were *meaningful, measurable* and *manageable*. Patient and service findings permit aeromedical service providers, payers, and planners to evaluate whether current service provisions are hitting their intended mark.

8.5 Thesis aim 4

The fourth and final aim of this thesis described rural clinicians' self-reported perceptions of the supports and barriers as they requested aeromedical retrieval for patients with suspected appendicitis in Central Queensland (Chapter 7). The results found that the decision to request aeromedical retrieval was a shared process, and identified a collegial culture which supported the asking of questions and not expecting to have all the answers as vital for the smooth running of this process. The perceived barriers were a lack of receiving clinicians' understanding of transfer agreements, and a lack of data connectivity. Clinician pessimism was identified as affecting perceived patient outcomes. Prior to study 4's commencement, there was a gap in understanding rural clinicians' self-reported perceptions of requesting aeromedical retrieval in Central Queensland hospitals as they care for suspected appendicitis patients.

The findings of clinician perceptions of appendicitis frequency provided insights into the aeromedical data results of high frequency appendicitis admissions[47]. The effect of the multiple methods approach from each of the studies has built upon and enhanced the exploration of clinician perceptions of the supports and barriers of requesting aeromedical retrieval for suspected appendicitis patients. The ‘hub and spoke’ regional referral structure is interconnected. The interconnectedness supports applying Systems Theory[2] to the research. However, further research of other aeromedical referral regions in Queensland is needed to explore the adaptive behaviour variation in other regions. Complex Adaptive Systems Theory[3] of nuanced variation in regional areas is why patient and service outcomes should ideally be analysed by regional services and not solely from state-wide analysis.

Enhanced concepts of regionalisation

The concept of regionalization was introduced in chapter 1, section 1.7.1, which described the advantages, risks and barriers to the ‘hub and spoke’ structure [48-51]. Based on the findings from study 4, additions and subtractions were made to the previous, accepted ‘advantages and barriers’ list of regionalisation. Additions 1-4 are advantages to regionalisation, whereas 5 and 6 are barriers to regionalisation.

1. Professional support from centralised communication centre regarding patient management and transport logistics for aeromedical and ground transport.
2. Enhanced sense of teamwork in rural locations.
3. Improved assessment skills for clinicians at rural hospitals.
4. Beneficial shared decision-making and mutual respect.
5. Staff frustration from receiving facility clinicians’ lack of understanding of the transfer process and rural hospitals’ resource limitations.

6. Rural clinicians’ feelings of pessimism for perceived patient outcomes.

New insights from Study 4 meant there was one subtractions from the previous list.

1. Reduced clinical skill and expertise at the ‘spokes’.

The findings from study 4 gained insight to the rural clinicians’ perceptions of requesting aeromedical services for suspected appendicitis patients, but little is known about clinicians at receiving facilities and their self-reported perceptions of their knowledge, skills, attitudes, challenges, and supports in the process of accepting aeromedical transfers for patients sent from rural hospitals with suspected appendicitis.

The results of the clinician interviews have helped to fill the previous knowledge gap of clinicians’ perceived strengths and barriers, and will help future improvement planning for rural clinicians requesting aeromedical retrieval in Central Queensland hospitals as part of a regional referral structure. Six recommendations informed by Study 4 are discussed in section 8.8 (recommendations 8, 9, 12, 16, 20 and 21).

8.6 Strengths of the thesis

Aeromedical research through the eyes of a female ICU nurse

Aeromedical research in the past has been dominated by males with medical credentials. A review of the reference list will confirm this observation, if one assumes that first names such as James or Samuel are male. By contrast, research that is undertaken by an experienced female ICU nurse such as this thesis takes on the quality of ‘whole-of-patient’ perspective (the basis of nursing philosophy[52]) which sets the research apart from the majority of past aeromedical research which has male and medical origins. Such diverse thinking is unique and adds to better understanding of the topic as it is from a different perspective.

Relating to data linkage

Linked data in Central Queensland has created new insights into aeromedical patients and their journeys. Notably, data linkage with a single patient identifier highlighted patterns of multiple patient flights in Central Queensland. This was achieved by high match rates (i.e., identical unique identifiers from two different sources) between unique RSQ patient identifiers and Queensland Health Statistical Service Branch (QHSSB) master linkage file unique identifiers. At the start of study 2, match rates averaged 71.2%. QHSSB applied data cleaning strategies and the match rate raised to 95.9%. However, it wasn't until after the inclusion of RFDS and LRM data coupled with further successful data cleaning strategies, requested from study 2, that the match rate increased to 98.1%. Other unique approaches in study 2 and 3 included multiple flights that were either escalating or back-transfers were not published, to the best of my knowledge, prior to this study.

Novel referral transfer movements

Two novel approaches to referral transfer movements were identified. The first were transfer movements relating to the hospital and health service boundaries (Intraregional, 'INTO region' and 'OUT of region') called 'aeromedical regional referral pathways'. The second were transfer movements between the capability levels of care (rural hospital-to-regional hospital, regional hospital-to-tertiary hospital and rural hospital-to-tertiary), called 'aeromedical referral progression pathways'.

Multiple methods

Using multiple-methods approach to describe quantity outcomes for patients and services and to deepen understanding of the rural and remote clinicians' decision-making process when requesting aeromedical retrievals was a strong decision[47]. To the best of my knowledge, this was the first study seeking to understand rural sending-clinician perceptions, supports, and barriers when requesting aeromedical services. These novel approaches to the subject of aeromedical retrieval have contributed to the understanding of aeromedical patient and service outcomes. The results are representative of aeromedical services in Central Queensland and this thesis has produced unique and compelling findings.

Catalogue of aeromedical outcome measure in codes and themes

The scoping review resulted in a new catalogue of outcome measures ordered by codes and themes. The themes, when placed in the new aeromedical quality framework, provided a visual representation of which quality measures may be missing. Discovery of knowledge gaps provides opportunities for future researchers to fill those gaps.

Structure and function of an aeromedical quality framework

The creation of an aeromedical quality framework was unique to aeromedical retrieval. To the best of my knowledge, this is the first aeromedical framework to combine two highly respected and referenced sources and apply it to aeromedical outcome themes to explore the strengths and areas for improvement of service provision. The function of the framework was flexible to accommodate the service provision of an aeromedical service, and also for service provision within a regional referral region. This work is important to produce more accurate evidence for decisions of health resource allocations across the referral region.

8.7 Thesis Limitations

Relating to data

Limitations of this thesis include potential missing and/or incorrect data in the quantitative analyses in study 2 and 3[54]. Author Delgado states missing data may "impair the ability of future studies to make conclusions on analyses"[55] (p.222), but the strengths of the data linkage minimise these limitations due to rigorous data linkage methodologies facilitated by Queensland Health Statistical Service Branch.

The period of data collection was time-limited, as the study period was from 1 January 2011-31 December 2015 and the death registry data was code up to 30 June 2019. However, the strength of the study was to highlight how linked data analysis of aeromedical patients' journey outcomes can be used in a previously created quality framework to explore regional referral pathway variations, which overall study findings are unable to achieve.

Relating to the study design

The generalisability of the thesis results, both quantitative and qualitative, are subject to certain challenges. There is considerable heterogeneity among air ambulance service structures and processes, as discussed in the introduction chapter. However, the detail in describing the study settings and the methods of the thesis allows the reader to select results applicable to their own setting.

In general, retrospective observational studies present a potential problem of inaccurate chart coding. These limitations were discussed in publication 2[18]. Authors Berthelot et al., explored data extracted from large hospital discharge databases and found a "small to modest effect" on study stability due to inaccurate chart coding. However, the chart coding is (sic) "generally adequate."[56] (p. 521). There are limitations in retrospective cohort studies, such as study 2 and 3, but using administrative datasets have been used to minimise these limitations. Additionally, use of the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines improves the quality of reporting this study.

Finally, the range of outcome measures could be broadened if the literature search could have been expanded to languages outside of English. However, the authors' English-only language comprehension did not provide this opportunity.

8.8 Public health recommendations

My intention for this body of work was to provide novel and rigorous evidence to improve the practice of aeromedical services and patient outcomes. Each publication includes discussion of service and patient outcome implications. The majority of these recommendations have been put forth in the publications and/or in the body of this thesis. However, there is value in elucidating the actual and potential public health implications and recommendations, sorted into one of five healthcare domains: practice, education, leadership, policy, and research[5]. My top three overall recommendations are listed first.

***Top three overall recommendations*:**

Recommendation 1:

Ongoing analysis of Queensland-wide linkage through the lens of regional referral pathways and referral progression pathways.

Recommendation 2:

Further analysis into high-frequency pathologies found in aeromedical patients, including stroke and cardiac pathologies, emergency general surgery, partial colectomy, small-bowel resection, cholecystectomy, operative management of peptic ulcer disease, lysis of peritoneal adhesions, and laparotomy.

Recommendation 3:

Include Queensland Ambulance Service data for paramedic clinical aeromedical data, ground transportation time intervals, and BROLGA data items into regional referral pathways and referral progression pathways analysis.

Healthcare practice:

Recommendation 4:

Promote further feasibility assessments of the aeromedical quality framework created in this thesis against actual performance criteria in services outside of Queensland.

Recommendation 5:

Further research to customise and tailor key performance indicators (KPI) in health districts' unique disparities based on linked data analysis of regional referral pathways.

Recommendation 6:

Further research on optimal referral pathways (e.g., flights from Rockhampton are referred to North Brisbane, but the closest facility may be Sunshine Coast hospital).

Recommendation 7:

Further regional referral pathway analysis to identify flight patterns, which may inform base location, crew mix, availability patterns, and aircraft allocation.

Healthcare education:

Recommendation 8:

Provide cultural awareness training for aeromedical retrieval clinicians (identified in the scoping review, chapter 2).

Recommendation 9:

Offer workshops to regional clinicians to better understand rural hospitals' limited scope of services (identified in the scoping review, chapter 2).

Recommendation 10:

The final healthcare education recommendation is from personal experience during my candidature. I have found significant interest from fellow nurses regarding my experience with the statistical computing software R Studio. Therefore, I encourage participation in classes offering statistical computing skills, like R, to all levels of direct patient care providers, especially nurses. Nurses with domain knowledge and expertise in patient care and hospital systems should be involved with health care research. Their perceptions of health problems and solutions have significant value. Enabling nurses with skills in R will help to explore data more efficiently.

Healthcare leadership:

The thesis has produced cooperative significance and collaborative gains among the leaders in diverse disciplines, including aeromedical providers such as Retrieval Services Queensland, LifeFlight Retrieval Medicine, and the Royal Flying Doctor Service, health system provider Central Queensland Health and Hospital Service, James Cook University, and partner research organisation Commonwealth Scientific and Industrial Research Organisation (CSIRO). Several of these relationships were new at the commencement of the study.

Recommendation 11:

Nurture the relationships with these leaders from this diverse range of organisations and continue to commit to the interconnected, 'whole-of-system' approach in order to increase the understanding of aeromedical patient and service outcomes.

Recommendation 12:

Healthcare leaders promote active teamwork and workplaces that encourage honest communication (identified in chapter 7).

Healthcare policy:

The findings from my quantitative and qualitative studies have aligned with the four following Queensland and National policy strategies. Firstly, an increased general understanding of aeromedical retrieval and transfer to/from rural and remote communities is a step forward toward the National goal of equitable and accessible healthcare from the National Health and Hospitals Reform Commission 2020-2025[58]. Secondly, the study findings have aligned with the 2026 Queensland eHealth strategy, that "access to the right information at the right place, at the right time is the key to the provision of high quality, valued healthcare services, improved patient outcomes, and reduced patient risk"[59]. This was done by linking the aeromedical patient journeys along their continuum of care, because without data linkage analysis patient outcomes were unknown. Thirdly, the thesis findings explored the Queensland Health policy for IHT, which requires direct hospital admission for stable patients unless they have "an undifferentiated condition requiring specific investigations or have deteriorated in transit, necessitating ED intervention"[60] (Queensland Health Requirement 3.1.5). Lastly, the study has aligned with initiatives from the Queensland Health Metropolitan emergency department access plan for a more coordinated IHT process and better coordination and integration improving access to emergency services in Queensland[61] by exploring aeromedical interhospital transfers in CQHHS.

Recommendation 13:

The scoping review found an absence of publications related to aeromedical patient comfort and satisfaction. However, healthcare service measures would typically include patient comfort and satisfaction[62]. In emergency scenarios, patients may not be able to verbalise pain or discomfort. In those situations, patients' facial grimacing is a substitute measure of comfort and absence of pain[63]. In addition, it may be inappropriate in traumatic, emergency scenarios to request immediate patient satisfaction surveys from the patient or family. However, respectful follow-up communication may provide insight into patient and family satisfaction with the service. Therefore, the recommendation is the development of a patient comfort and satisfaction reporting policy to increase understanding of the aeromedical patient experience.

Recommendation 14:

Further policies surrounding pre-aeromedical transport holding areas at tertiary hospitals for patients transporting to lower level care, and research to explore its impact on reducing bed block (identified in chapter 5 and chapter 6).

Recommendation 15:

Examine the coordination of ground and aeromedical services through a policy which develops and implements precise event time definitions (identified in the scoping review, chapter 2).

Recommendation 16:

Propose policy which encourages shared decision-making and mutual respect among hospital staff clinicians (discussed in publication 6).

Recommendation 17:

Future governance which promote standardisation of one grand aeromedical event time for service providers, called Comprehensive Patient Journey Time (identified in the scoping review, chapter 2).

<u>Healthcare research:</u>

Recommendation 18:

Healthcare provision is centred on people; individuals, families, communities and society[63]. Healthcare structures and processes work to improve people's health and wellbeing[63]. Therefore, the first focus of healthcare research should be on the structure, process, and outcomes of aeromedical patients' journeys. Exploring service provision and outcomes centred on the patients' journeys maintains that focus. Consequently, I recommend further outcome studies be conducted centred on the aeromedical patients' journeys.

Recommendation 19:

Benchmarking study finds over time and across other air ambulance services nationally and internationally.

Recommendation 20:

Conducting qualitative studies of clinicians regarding frequent aeromedical users to explore specific differences among populations by condition, such as mental illness and heart failure[64].

Recommendation 21:

Research the availability of diagnostic imaging services in rural-level hospitals for emergency general surgery patients who require aeromedical interhospital transfer (identified in study 4).

Recommendation 22:

Future analysis of the State-wide data linkage should include rates of overtriage (OT), potentially avoidable transfers (PAT), and long delays for back-transfers to lower levels of care. These insights will help to guide sustainable service planning (discussed in publication 4 and 5).

Recommendation 23:

Further linked data analysis of staffing levels, bed availability, available hospital services, and capacity at referring and receiving facilities (discussed in publication 4 and 5).

Recommendation 24:

Further research to establish pre-threshold alarms (i.e., upward utility trends that may indicate volume stress and put pressure on safe, appropriate, early intervention and transfers) in each of the three referral pathways (identified in the scoping review, chapter 2).

8.9 Knowledge translation

Knowledge translation (KT) is an active process and is critical for public health research as KT moves "knowledge to action Knowledge translation to improve health"[1]. The following section describes the steps to plan for knowledge dissemination and implementation.

It has been identified that a potential challenge in the creation of linked data is social organization[65]. Authors Holman et al., state "data linkage (sic) demands leadership, inter-agency, and inter-sectoral cooperation, a dedicated group of users who drive reforms and perseverance"[66] (p.775). Ottawa's knowledge translation model was selected to strategize the synthesis and dissemination of this thesis' findings[1]. The first three steps in the knowledge translation model have been completed in the body of this thesis. The term 'innovation' has been exchanged for 'findings':

1.) Identify the need

2.) Identify the findings

3.) Assess the findings, potential adopters, and the environment for barriers and facilitators.

Steps 4-6 in the knowledge translation model will complete the plan:

4.) Select and monitor the knowledge translation strategies

5.) Monitor findings adoption

6.) Evaluate outcomes of the findings

In step 4 of the knowledge translation model, “select and monitor the knowledge translation strategies”, the goals are to generate awareness, interest, and policy change, to impart knowledge, and to inform robust aeromedical research in the near future. These strategies include presentations or posters at conferences such as the Aeromedical Society of Australasia, Queensland Health hospital research conference, and media campaigns. Fortunately, video and photos of helicopters and fixed-wing aircraft provide exciting and thrilling high-impact news stories. The knowledge translation process has already integrated researchers and research users, such as ED consultants, retrievalists, academics and CSIRO researchers, and QH leaders that have come together to design these studies.

In step 5 of the knowledge translation model, “monitor findings adoption”, requires a measure of how the findings have spread through aeromedical and health service organisations and how effectively has the aeromedical framework been utilised in reporting performance indicators. Additionally, the acceptance of State-wide data linkage analysis through the lens of regional referral pathways and referral progression pathways in reporting on aeromedical outcomes will indicate that the knowledge translation strategies have been sufficient.

In step 6 of the knowledge translation model, “evaluate outcomes of the findings”, the effectiveness of the findings should be determined by the incorporation of patient outcome measures from state-wide analysis of regional referral pathways and referral progression pathways in yearly public reporting. Each of the twenty-four recommendations evaluate outcomes of the findings.

8.10 Thesis conclusion

Aeromedical retrieval remains a vital link for patients to access appropriate health care in Central Queensland. The patient and service outcomes from linked health service data before and after flight were largely unknown prior to the commencement of this thesis. This study provides an exploration of patient age, sex, illness, sending location, mortality, per-patient flight frequency, and service analysis of sending and receiving locations, transfer type, regional referral pathways, referral progression pathways, crew mix, aircraft type, service time intervals, ARIA+ classifications, admission pathways, hospital and ED length of stay, disposition, and priority categories to fill the previous gaps in knowledge.

The data linkage match rates were improved by the study's inclusion of data from the aeromedical service providers LifeFlight Retrieval Medicine and Royal Flying Doctor Service (Queensland). The data cleaning and preparation of the aeromedical sources identified overlaps or 'shared' information which were combined and formed each aeromedical episode and identified three types of time interval gaps. The study successfully linked data from aeromedical, ED, in-hospital and death sources and explored the aeromedical patients' journeys. Future work in the area of data linkage analysis will be strengthen with this information.

This thesis also developed an aeromedical quality framework from the result of a scoping review and used it to report existing aeromedical patient and service outcomes from linked data. The framework will help guide prehospital and in-hospital performance reporting. With variations between regional referral pathways, this knowledge will aid with planning within the local service.

This study provides insight to rural clinicians' self-perceptions of the retrieval process and provides new knowledge on aeromedical retrieval. It identified not knowing patient outcomes as a barrier to clinicians' reflective practices. The steps to knowledge dissemination and implementation includes increasing awareness for receiving clinicians to the limitation of rural services to improve timely patient care transfers. These are original contributions to the advancement of knowledge. Integration of the findings in this thesis will help to plan future public health practice, education, leadership, policy, and research, which will improve patient care in the Central Queensland region and in the State of Queensland. The collective outcome of the thesis provides information for hospital and health services and aeromedical providers, payers, and planners to implement regional referral pathway and referral progression pathway analysis with state-wide data linkage, which will inform future policy, strategy development, and improvement.

The draft aeromedical quality framework derived from the literature provides a sound basis for a comprehensive -performance evaluative framework, and was largely validated by the primary data explored in this research. However, there are weaknesses in the data availability and also complex factors identified that influence the various performance indicators that make its adoption straightforward. Further research is needed to test the significance and utility of the framework and it component elements.

8.11 Chapter references

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Appendices

Appendix A. Outputs and awards

Presentations during candidacy

2020-January 2022: Scheduled presentations cancelled or postponed due to Covid

Edwards, K.H. (2022). *What is the value of aeromedical patient and service linked data?* Presented at the Aeromedical Society of Australasia 2022: Critical care in the air – critical care anywhere, Brisbane, Queensland 30-1 September 2022.

Edwards, K.H. (2021). *Understanding the Aeromedical Patient Journey and Outcomes in Central Queensland: A Linked Data Study.* PhD Pre-completion Seminar (online). 12 November 2021.

Edwards, K.H. (2019). *Aeromedical patient outcomes in Central Queensland: A linked data study.* Invited presenter: Central Queensland Hospital and Health Service Clinical Council. Rockhampton, QLD, 14 March 2019.

Edwards, K.H. (2018). *Air ambulance outcome metrics: A systematic review of quality attributes and service delivery domains*. Aeromedical Society of Australasia (ASA) 2018: Aeromedicine: the next 30 years, Hobart, Tasmania, 26-28 September 2018.

Edwards, K.H., Edwards, M.T. (2018). *Aeromedical Research.* University of Queensland Rural School, Rockhampton, QLD, 15 August 2018.

Edwards, K.H. (2018). *Measuring quality care in air ambulance outcomes*. PhD Cohort Conference. Townsville, 19 July 2018.

Edwards, K.H. (2017). *Linking the pieces together: The aeromedical patient journey*. 3MT presented at the Health Service and Policy Research (HSRAANZ) 2017: Shifting priorities: balancing acute and primary care services, Gold Coast, Queensland, 1-3 November 2017.

Edwards, K.H., Franklin, R., Elcock, M., Aitken, P., Edwards, M. (2017). *A data linkage and patient outcome study of aeromedical retrieval services in Central Queensland*. Oral poster presented at the Health Service and Policy Research (HSRAANZ) 2017: Shifting priorities: balancing acute and primary care services, Gold Coast, Queensland, 1-3 November 2017.

Edwards, K. (2015). *Interhospital transfers via fixed and rotor wing retrieval to a regional Central Queensland ED.* Project proposal paper presented at the Aeromedical Society of Australasia 2015: Expanding Frontiers, Darwin, Northern Territory 19-21 August 2015.

Grants, scholarships and awards during candidacy

Research Grants

- Central Queensland Hospital and Health Service Match Grant, Principal Investigator 2017
- Queensland Emergency Medicine Foundation Research Grant, EMPJ-370R27-2017
- Queensland Emergency Medicine Foundation Research Grant, EMPJ-363R25-2016
- Queensland Emergency Medicine Foundation Research Grant – Collaborative, 2015

Research Scholarships, Awards and Honours

- Industry Mentoring Network in STEMM (IMNIS) selected pilot member 2020
- CSIRO Health and Biosecurity Top-up Scholarship 2018-2020
- Three minute thesis (3MT) James Cook University People's Choice Award 2018
- 3MT College of Public Health, Medical and Veterinary Science winner 2018
- Research Master Essay Award – Quality in Postgraduate Research April 2018
- 3MT People's Choice Award Australia and New Zealand Health Service and Policy Research conference 2018.
- Australian Postgraduate Award James Cook University – January 2018-June 2020
- James Cook University PhD Cohort Program 2017 until completion

Appendix B. Quantitative data sources

Data values and descriptions

Clinical Coordination Retrieval Information Systems (CCRIS)

Clinical Coordination and Retrieval Information Systems (CCRIS) Values

Column Name	Description
patient_id	Unique patient ID
birth-year	In yyyy format
Agedays	In dd format
Agemonths	In mm format

Ageyears	In yyyy format
PersonSex	FEMALE, MALE, or N/A
DateofRequest	The date the call/request for either advice or retrieval came to RSQ
TimeofRequest	The time the call/request for either advice or retrieval came to RSQ
DateofRetrieval	Not validated by RSQ
QCCAssessedMinEscortLvl	Crew escort determined by RSQ coordinator
RetrievalEscortOUTCOME	Crew escort outcome.
TeamMember1	Team member one
TeamMember2	Team member two
Priority	Priority 1 = 1hr, Priority 2 = 1-3hrs, Priority 3 = 3-6hrs, Priority 4 = 6-24hrs, Priority 5 = 24+hrs, N/A = data not entered
TransportType	Road; Rotary Wing; Fixed Wing; Boat; Other; or N/A
TASK	Advice=no flight, advice given, IHT=from clinic (any type of 'facility'), Primary=scene-type call
Sendingname/ Referring_Facility_Name	The health facility that has requested the retrieval
SendingHHS/ReferringHHS	The HHS that the Referring Facility Name belongs too
SendingLocailty	Sending locality name
Receivingname	Receiving name
ReceivingHHS/ Receiving_HHS_Name	Receiving HHS name
ReceivingLocailty	Receiving locality name
QCCIllnessAssessment	the high level medical reason for transport
TimeofActivation	Time of crew activation
Team1stDoc.Source	First doctor source
Team2ndDoc.Source	Second doctor source
Team1stParamedicSource	First paramedic source
Team2ndParamedicSource	Second paramedic source
Team1stRNSource	First nurse source
Team2ndRNSource	Second nurse source

Queensland Neonatal Emergency Transportation Systems (QNETS) Values

Column Name	Description
patient_id	The unique patient ID
birth-year	Format yyyy
Agedays	Format dd
Agemonths	Format mm
Ageyears	Format yyyy
PersonSex	FEMALE, MALE, or N/A
DateofRequest	The date the call/request for either advice or retrieval came to RSQ

TimeofRequest	The time the call/request for either advice or retrieval came to RSQ
DateofRetrieval	Date not validated by RSQ
TimeofActivation	Time of activation
DateofActivation	Date of activation
QCCAssessedMinEscortLvl	Crew escort determined by RSQ coordinator
RetrievalEscortOUTCOME	Transport outcome.
TeamMember1	Team member one
TeamMember2	Team member two
Priority	Priority1 = 1hr, Priority2 = 1-3hrs, Priority3 = 3-6hrs, Priority4 = 6-24hrs, Priority5 = 24+hrs, N/A = data not entered
TransportType	Road; Rotary Wing; Fixed Wing; Boat; Other; or N/A
TASK	Advice=no flight, advice given, IHT=from clinic (any type of 'facility'), Primary=scene-type call
Sendingname /Referring_Facility_Name	The health facility that has requested the retrieval
SendingHHS/ReferringHHS	The HHS that the Referring Facility Name belongs too
SendingLocailty	Name of sending locality
Receivingname	Name of receiving facility
Receiving_HHS_Name	Name of receiving HHS
ReceivingLocailty	Name of receiving locality
TimeofActivation	Time of crew activation
Team1stDoc.Source	First doctor source
Team2ndDoc.Source	Second doctor source
Team1stParamedicSource	First paramedic source
Team2ndParamedicSource	Second paramedic source
Team1stRNSource	First nurse source
Team2ndRNSource	Second nurse source
ANZPICDiagnosisType	the high level medical reason for transport
ANZPICCodeDescription	the high level medical reason for transport

Royal Flying Doctor Service (RFDS)

Royal Flying Doctor Service (RFDS) Values

Column Name	Description
TRANSPORT_TYPE	Inter-hospital transfer
PROVISIONAL_DIAGNOSIS	provisional diagnosis
SECONDARY_DIAGNOSIS	secondary diagnosis
ICD_CODE	
LEVEL_1_GROUPING	ICD level 1 groupings
LEVEL_2_GROUPING	ICD level 2 groupings

LEVEL_3_GROUPING	ICD level 3 groupings
LEVEL_4_GROUPING	ICD level 4 groupings
PREDICTED_LEVEL_OF_CARE	No Dependency, Low Dependency, High Dependency, Critical
PROVIDED_LEVEL_OF_CARE	No Dependency, Low Dependency, High Dependency, Critical
RSQ_TRIAGE_CATEGORY	1, 2, 3, 4, 5
ESCORT1	Specialist, Anaesthetic / ICU M2.2, Registrar, Emergency M3.1, Registrar, Anaesthetic / ICU M3.2, Specialist, Emergency M2.1, Registrar, Paediatric / Neonatal M3.4
ESCORT2	Specialist, Anaesthetic / ICU M2.2, Registrar, Emergency M3.1, Registrar, Anaesthetic / ICU M3.2, Specialist, Emergency M2.1, Registrar, Paediatric / Neonatal M3.4
ESCORT3	Specialist, Anaesthetic / ICU M2.2, Registrar, Emergency M3.1, Registrar, Anaesthetic / ICU M3.2, Specialist, Emergency M2.1, Registrar, Paediatric / Neonatal M3.4
ESCORT4	Specialist, Anaesthetic / ICU M2.2, Registrar, Emergency M3.1, Registrar, Anaesthetic / ICU M3.2, Specialist, Emergency M2.1, Registrar, Paediatric / Neonatal M3.4
Sending_Facility_Name	Sending facility name
Sending_HHS	Sending HHS name
Receiving_Facility_Name	Receiving facility name
Receiving_HHS	Receiving facility name
Base_Name	Base name
Base_Type	Base type e.g., traditional, Non traditional
contract_type	Base contract type
LEG_NUMBER	Pilot recorded legs in aircraft
NUMBER_PATIENTS	Number of patients on board
MRT_FLYING_TIME	Pilot recorded flight time
UPLIFT_AIRSTRIP	(lic)licenced airstrip, unlicenced(paddock)
DESTINATION_AIRSTRIP	destination airstrip
DATETIME_ACTIVATION	datetime activation
DATETIME_FIRST_CONTACT	Datetime first contact with patient
DATETIME_DEPART_WITH_PATIENT	Datetime depart with patient
DATETIME_HANDOVER	Time medical team handover care

DATETIME_AFR_LEG_ARRIVE	AFR_LEG_DEPART and AFR_LEG_ARRIVE.
DATETIME_AFR_LEG_DEPART	AFR_LEG_DEPART and AFR_LEG_ARRIVE

LifeFlight Retrieval Medicine (LRM)

LifeFlight Retrieval Medicine (LRM) Values

Column Name	Description
DATE_RETRIEVAL_REQUESTED	Date of retrieval request
TEAM_ACTIVATED_DATE	Date team was activated for flight
TEAM_ACTIVATED_TIME	Time team was activated for flight
READY_TO_DEPART_DATE	Date team was ready for departure
READY_TO_DEPART_TIME	Time team was ready for departure
DEPART_WITH_MEDICAL_TEAM_DATE	Date the medical team departed
DEPART_WITH_MEDICAL_TEAM_TIME	Time the medical team departed
LAND_AT_DESTINATION_DATE	Date the asset landed at destination
LAND_AT_DESTINATION_TIME	Time the asset landed at destination
AT_SCENE_PATIENT_DATE	Date team with patient
AT_SCENE_PATIENT_TIME	Time team with patient
DEPARTURE_READY_DATE	Date ready for departure
DEPARTURE_READY_TIME	Time ready for departure
ACTUAL_TIME_DEPART_DATE	Date actual ready for departure
ACTUAL_TIME_DEPART_TIME	Time actual ready for departure
ARRIVE_AT_RECIEVING_HOSPITAL_DATE	Date arrive at receiving hospital
ARRIVE_AT_RECIEVING_HOSPITAL_TIME	Time arrive at receiving hospital
DEPART_RECIEVING_HOSPITAL_DATE	Date depart receiving hospital
DEPART_RECIEVING_HOSPITAL_TIME	Time depart receiving hospital
ARRIVE_BACK_AT_BASE_DATE	Date arrive back at base
ARRIVE_AT_RECIEVING_HOSPITAL_TIME	Time arrive at receiving hospital
AVAILABLE_FOR_NEXT_TASKING_DATA	Date available for next tasking
AVAILABLE_FOR_NEXT_TASKING_TIME	Time available for next tasking
Priority	Priority status e.g., 1-5
PRIORITY_CATEGORY	Priority status Category 1-5.
CHIEF_TRANSPORT_PLATFORM	e.g., Rotary Wing, Fixed Wing, Road
MISSION_TYPE	e.g. interhospital transfer, primary response

REFERRING_HOSPITAL_AUST	Name of referring hospital
RECEIVING_HOSPITAL_AUST	Name of referring hospital
DIAGNOSIS_DETAILS	Diagnosis details
DOCTOR_1_DESIGNATION	Doctor 1 e.g., Consultant,Registrar
DOCTOR_2_DESIGNATION	Doctor
PARA_NURSE_1_DESIGNATION	Paramedic or nurse 1e.g., Nurse, Paramedic

Emergency Department Information Systems (EDIS)

Emergency Department Information Systems (EDIS) Values

Column Name	Description
person_id	created person id
principal_icd_code	Principal diagnosis ICD code
principal_icd_desc	Principal diagnosis description
other_icd_code1	Other diagnosis 1 ICD code
other_icd_desc1	Other diagnosis 1 description
other_icd_code2	Other diagnosis 2 ICD code
other_icd_desc2	Other diagnosis 2 description
age	age at time of presentation
gender	gender
fclty_name	Facility name
facility_hhs	Facility HHS
patient_hhs	Patient HHS (where available)
patient_state	Patient state of residence (QLD/other - where available)
triage_datetime	Date and time of triage
triage_category	Triage category
service_start_datetime	Service commencement date and time
episode_end_status_code	Episode end status code
episode_end_status_desc	Episode end status description
arrival_mode_code	Mode of arrival code
arrival_mode_desc	Mode of arrival description
arrival_datetime	arrival date and time
episode_end_datetime	Episode end date and time
phys_depart_datetime	Physical departure date and time

arrive_to_depactual_mins	arrival time to actual departure time (i.e. - length of stay, in minutes)
arrive_to_depready_mins	arrival time to ready for departure time (minutes)
arrive_to_triage_mins	arrival time to triage time (minutes)
arrive_to_treat_mins	arrival time to treating clinician seen (or 'service start', in minutes)
pd_retr_match	flag indicating match between presentation date and retrieval date

Queensland Hospital Admitted Patient Data Collection (QHAPDC)

Queensland Hospital Admitted Patient Data Collection (QHAPDC) Values

Column Name	Description
episode_id	admission episode
AGE	age at time of admission
SEX	sex of patient
FCLTY_NAME	name of facility - private facilities marked as such
START_DATE	start date and time of admission
END_DATE	end date and time of admission
TFR_TO_FCLTY_ID	Transferring to facility ID (public hospitals only)
EPIS_TYPE	Care type
ADM_UNIT	Admission unit
SEPNMODE	separation mode
ORIG_REF_CODE	origin of admission
PAT_DAY	patient days (uncapped)
DRG	DRG (V6.0)
SD_RETR_MATCH	flag indicating match between start date and retrieval date
ED_RETR_MATCH	flag indicating match between end date and retrieval date

Death Registry

Death Registry Values

Column Name	Description
person_id	CD coded cause of death - available for registrations to calendar year 2013
CAUSE_OF_DEATH_CODED	Text cause of death available for all years
CAUSE_OF_DEATH_TXT	cause of death - uncoded text (all years)
POST_CODE	postcode
CORONR	Y or N

DATE_DEATH	yyyy/mm/dd Day of the week of death
Death location	"HOSP" or "OTHER"
HHS of usual Residence	HHS of deceased person's usual residence - available for registrations to calendar year 2013

Valuables >85% missing and not used in study

EDIS value	Missing %
other_icd_code1	99%
other_icd_desc1	99%
other_icd_code2	99%
other_icd_desc2	99%
RFDS values	**Missing %**
BIRTH_IN_TRANSIT	100%
ETT_DISLODGED_IN_TRANSIT	100%
INTUBATION_DELAY	100%
THORACOTOMY	100%
CARDIAC_PACING	100%
CARDIOVERSION	100%
FLUID_RESUSCITATION_TRAUMA	99%
HYPOTHERMIA_IN_TRANSIT	99%
MAJOR_PROCEDURE_IN_TRANSIT	99%
THORACOSTOMY	99%
DEFIBRILLATION	99%
ETT_INTUBATION	99%
HYPOXIA_IN_TRANSIT	98%
CARE_GREATER_THAN_PREDICTED	97%
Airway_Procedure_LMA	100%
Airway_Procedure_Needle_Cricothyroidotomy	100%
Breathing_Procedure_Emergency_Needle_Decompression	100%
Breathing_Procedure_Open_Thoracostomy	100%
Circulation_Procedure_CPR	100%
Circulation_Procedure_Defibrillation	100%
Circulation_Procedure_Cardioversion	100%
Circulation_Procedure_Haemorrhage_Control	100%
Circulation_Procedure_Pacing_Transcutaneous	100%

Circulation_Procedure_Balloon_Pump	100%
Other_Procedure_Regional_Nerve_Block	100%
Airway_Procedure_OPANPA	99%
Airway_Procedure_Intubation	99%
Airway_Procedure_Intubation_in_Transit	99%
Airway_Procedure_Surgical_Airway	99%
Breathing_Procedure_NIV	99%
Breathing_Procedure_Invasive_Ventilation	99%
Breathing_Procedure_ICC_Right_side	99%
Breathing_Procedure_ICC_Left_Side	99%
Circulation_Procedure_IV1_Peripheral	99%
Circulation_Procedure_IV2_Peripheral	99%
Circulation_Procedure_Intraosseous_Needle	99%
Circulation_Procedure_CVC	99%
Circulation_Procedure_Inotropes	99%
Circulation_Procedure_Arterial_Cannulation	99%
Circulation_Procedure_Blood_Transfusion	99%
Circulation_Procedure_Retrieval_Blood_Used	99%
Circulation_Procedure_Haemorrhage_Control	99%
Circulation_Procedure_Pacing_Temporary_Internal	99%
Disability_Procedure_Arm_Splint	99%
Disability_Procedure_Pelvic_Splint	99%
Disability_Procedure_Cervical_Collar	99%
Disability_Procedure_Leg_Splint	99%
Other_Procedure_NGT	99%
Other_Procedure_OGT	99%
Other_Procedure_IDC	99%
Other_Procedure_FAST_Scan	99%
Disability_Procedure_VACMAT	98%
Monitor_Ventilaotry_Obs	97%
Monitor_ETCO2	97%
Breathing_Procedure_O2Mask	95%
QNETS values	**Missing %**
Team.1st.Paramedic.Source	99%
Team.1st.RN.Source	99%

Team.2nd.RN.Source.Priority	97%
Team.2nd.Paramedic.Source	96%
LRM values	Missing %
DELIVERY_IN_TRANSIT	100%
THORACOTOMY	100%
CARDIOVERSION	100%
CARDIAC_PACING_PACING_TRANSCUTANEOUS	100%
INTUBATION_ATTEMPT_4_DESIGNATION	100%
LMA	100%
RESCUE_LMA	100%
NEEDLE_CRICOTHYROIDOTOMY	100%
SURGICAL_AIRWAY	100%
EMERGENCY_NEEDLE_DECOMPRESSION	100%
OPEN_THORACOTOMY	100%
HFV	100%
NITROUS_OXIDE	100%
BALLOON_PUMP_IABP	100%
PACING_TRANSCUTANEOUS	100%
ECMO	100%
ANTI_VENOM_ADMIN	100%
ISOPOD	100%
CARDIAC_ARREST_DURING_TRANSIT	99%
DEATH_IN_CARE	99%
DEATH_AFTER_ARRIVAL_AT_RECEIVING_HOSPITAL	99%
ETT_DISLODGED_IN_TRANSIT	99%
ETT_INTUBATION_IN_TRANSIT	99%
INTUBATION_DELAY	99%
FLUID_RESUSCITATION_TRAUMA	99%
HYPOTHERMIA_IN_TRANSIT	99%
MAJOR_PROCEDURE_IN_TRANSIT	99%
THORACOSTOMY	99%
DEFIBRILLATION	99%
CARDIAC_PACING_PACING_TEMPORARY_INTERNAL	99%
INTUBATION_ATTEMPT_2_DESIGNATION	99%
INTUBATION_ATTEMPT_3_DESIGNATION	99%

OPA_NPA	99%
INTUBATION_ROUTINE	99%
INTUBATION_RSI	99%
INTUBATION_IN_TRANSIT	99%
NIV	99%
ICC_RIGHT_SIDE	99%
ICC_LEFT_SIDE	99%
FINGER_THORACOSTOMY	99%
INTRAOSSEUS_NEEDLE	99%
CVC	99%
ARTERIAL_CANNULATION	99%
BLOOD_TRANSFUSION	99%
RETRIEVAL_BLOOD_USED	99%
CPR	99%
PACING_TEMPORARY_INTERNAL	99%
HAEMORRHAGE_CONTROL	99%
THROMBOLYSIS	99%
C_SPINE_IMMOB_HARD_COLLAR	99%
C_SPINE_IMMOB_SOFT_COLLAR	99%
C_SPINE_IMMOB_OTHER	99%
ARM_SPLINT	99%
LEG_SPLINT	99%
IDC	99%
NGT_OGT	99%
FAST_SCAN	99%
EFAST	99%
REGIONAL_NERVE_BLOCK	99%
DATE_RETRIEVAL_REQUESTED	85%

Key: icd_desc – international classification of diseases description; CPR- cardiopulmonary resuscitation; ETT - endotracheal tube; LMA - laryngeal mask airway; OPANPA - oropharyngeal airway/nasopharyngeal airway; NIV- non-invasive ventilation; ICC- intercostal catheter; IV-Intravenous; CVC-central venous catheter; NGT-nasogastric tube; OGT-orogastric tube; IDC-indwelling catheter; FAST-focused assessment with sonography for trauma; VACMAT-vacuum split; HFV-high-frequency ventilation; IABP-intraortic balloon pump; ECMO-extracorporeal membrane oxygenation.

Data preparation

Data cleaning

File Structure and Naming

Data preparation began when EDIS, QHAPDC, QHAPADC morbidity, death and an ID look-up key were sent in five separate text files, by SSB to KHE through KiteWorks, a QH approved, password protected software with limited access periods. CCRIS and QNETS data were electronically sent to KHE in text form by RSQ with a separate password for security. Each of these seven files' structure were checked, using text editor. All were tab delimited format. No abnormalities existed and no alterations or clarification were necessary. These were saved separately into an excel document. Naming logic followed the file source. EDIS file was saved as EDIS.xlsx, QHAPDC was saved as QHAPDC.xlsx. QHAPDC morbidity was broken into four parts using text editor. A check was done to ensure continuity. This was saved in three excel sheets and named as QHAPDC-morb.xlsx. Death was saved as Death.xlsx, ID look-up key was saved as ID-LOOKUP.xlsx, CCRIS was saved as CCRIS.xlsx, QNETS was saved as QNETS.xlsx. The ID-LOOKUP.xlsx had the new person id key from SSB to match the unique patient id in CCRIS and QNETS, which was named, 'study_id'. A new excel document was created that copy/pasted the SSB ID-LOOKUP fields (person_id and study_id) and included two new columns; one that matched the CCRIS study id's and one that matched the QNETS study id's. This new document key was named and saved as, 'MatchingIDs.xlsx'. Then, another excel document was created and named, 'CCRIS-prep1', that in Sheet 1, pasted the new 'person_id' key into column A, associated 'study_id' in column B, these associated timestamps and clinical attributes in columns C:W. Then, sorted in person_id, date of request and time of request. Sheet 2 of this spreadsheet copied person_id, then filtered to get unique values and counts. Sheet 3 were calculations from maximum and minimum request date and request time to plot retrieval frequency. These same steps were executed for QNETS and saved as 'QNETS-prep1.xlsx'.

Map unique identifier and primary keys

Mapping was necessary due to the three phrases of data collection and the sharing from QHSSB data linkage team several unique identifiers and primary keys.

Nomenclature of unique identifier and primary keys throughout three phases of data sharing among three sources.

Data Collection Phase	Source	Unique Identifier Name	Primary Key Name
First	RSQ	Patient_Study_ID	-
Second	SSB	-	person_id
Third	SSB	old_person_id	-
Third	RFDS	PATIENTID	-
Third	SSB	-	new_patient_id

Abbreviations: RSQ: Retrieval Services Queensland; RFDS: Royal Flying Doctor Service; SSB: Statistical Services Branch.

1. Prepare RStudio. The working directory was set within a James Cook University password protected device. Required R packages were installed and libraries were loaded; reshape, plyr, data.table, stringi, lubridate, readlx.

2. Upload and read in old_person_id/ new_patient_id linkage key table in R. Name it 'links'.

3. Remove any episode representing new_patient_id that does not map to an old_person_id.

4. Upload and read in RSQ xlsx with three tabs; CCRIS. QNETS and LRM. Name these tabs, 's1', 's2' and 's3'.

5. Check row/column totals in R is equal to what is in excel. Document totals.

6. Create a unique CCRIS ('s1') person_id list, a unique QNETS ('s2') person_id list, a unique LRM ('s3') person_id list. Combine these lists and save as one new vector (upersonid). Identify and document the length of this vector.

7. Check upersonid to corresponding old_person_id in SSB key matches.

8. Create a new vector of missing old_person_id's. Count length of this vector and view structure of data. Make notes on answers to two questions; 1. Do all person_id's map to at least one new_patient_id? Do any person_id's match to more than one new_patient_id?

9. Create new vector when new_patient_id correspond with old_person_id's and upersonid.

10. Now focus on RFDS: Read in RFDS xlsx and its four tabs. Name the key tab, 'link2'. Name the remaining three activity tabs; 's4', 's5', 's6'. These unique identifier is called 'PATIENTID'.

11. Create a new vector of unique PATIENTID's from each tab. Name each; 's4PID', 's5PID', 's6PID'. Identify and document length. Check that this matches SSB summary documentation.

12. Create a new vector that combines 's4PID', 's5PID', 's6PID' and name it, 'RDSPATIENTID'.

13. Create new vector when new_patient_id keys corresponds with 'RDSPATIENTID' in 'PATIENTID'. Make notes on answers to two questions; 1. Do all 'RDSPATIENTID' map to at least one new_patient_id keys? Do any 'RDSPATIENTID's match to more than one new_patient_id keys?

14. Resolve cases with more than one mapping. Document findings.

15. This will create two new vectors; one that contains linkage between 'PATIENTID's and new_patient_id. Name and save it 'Link4'. The other will contain linkage between old_person_id and old_person_id. Name and save this vector 'Link5'. Document names of these two new vectors.

16. Create a new vector of unique Link4, name and save it 'uLink4' and a new vector of unique Link5, name and save it 'uLink5'.

17. Create a new vector when 'uLink4' PATIENTID is in RDSPATIENTID, name and save it 'urLink4'.

18. Create a new vector when 'uLink5' old_person_id's is in upersonid, name and save it 'urLink5'.

19. Merge 'urLink4' by both PATIENTID and by PATIENTID for all three vectors; 's4', 's5', 's6'. Name and save these three new vectors; 'news4', news5', 'news6'.

20. Create a new set of vectors for all PATIENTID that include those PATIENTID that did not map. Use code; all.y=T. Name and save these as ‘newS4’, ‘newS5’, ‘newS6’.

21. Identify those missing PATIENTID. Create a new vector with these unique missing PATIENTID. Name and save as, ‘missingIDsNewS4’.

22. Merge ‘urLink5’ by both old_person_id’s and by person_id’s for all three vectors; ‘s1’, ‘s2’, ‘s3’. Name and save these three new vectors; ‘newS1’, newS2’, ‘newS3’.

23. Upload and read in ED, QHAPDC and QHAPDC ward and death.

24. Create a new vectors with old_person_id that correspond with upersonid. Name and save as; ‘ed’, ‘qhapdc’, ‘death’, ‘ward’.

25. Create new vectors of unique id. Name and save as; ‘ed2’, ‘qhapdc2’, ‘death2’, ‘ward2’.

26. Merge ‘urLink5’ by both old_person_id’s and by old_person_id’s for all four vectors; ‘ed2’, ‘qhapdc2’, ‘death2’, ‘ward2’. Name and save these four new vectors; ‘newED’, ‘newQHAPDC, ‘newDEATH’ and ‘newWARD’.

27. Create one .RData folder which contain: ‘newS1’, newS2’, ‘newS3’, ‘newS4’, ‘newS5’, ‘newS6’, ‘newED’, ‘newQHAPDC, ‘newDEATH’, ‘newWARD’, ‘urLink4’ and ‘urLink5’. Name: identify that it’s ready to link, e.g., ‘ReadyToLink.RData’

28. Name and save R code.

29. Download .RData file and save as a .csv file

30. Remove all old ID’s from CCRIS, QNETS, LRM and RFDS.

31. Rename all files to source names and add ‘N’ to represent new version, in front of each for clarity. Document each file name, e.g., ‘NED.csv’, ‘NRFDS.cvs’ to OneDrive.

Format datetime, identify duplicates, create composite ID/time key

Steps to format datetime, identify duplicates, create composite ID/time key

1. Prepare RStudio. Required R packages were installed and libraries were loaded; reshape, dplyr, data.table, stringi, lubridate, readr. Set working directory. Set option stringsAsFactors=F.

2. Load, ‘ReadyToLink.RData’

3. Begin with CCRIS: Rename new_person_id to PID. Convert date and time of request and day of retrieval to Australian Eastern Standard Time (AEST). Convert to dd/mm/yyyy hh:mm datetime format.

4. Bring together converted Request datetime and new_person_id to create a unique ID. Name and save as 'cID' for combined ID. Then, cbind cID, PID, RequestDT, RetrievalDate to form a new vector, 'C1'.

5. Identify non-unique cID's. Create new check vector, 'chk'.

6. Create new vector when C1 is duplicated, Name and save as 'DuplicatedC1'. And also a vector when CI is unique, name and save as, 'C2'.

7. Review duplicate CCRIS cases. Document findings. Create new vector with these removed cases. Name and save as 'C4'.

8. Follow same steps for episodes with cancellations based on NA in Retrieval date and also in 'TransportType' attribute == "CANCELLED", "ADVICE", "OTHER" or "NA". Name and save as; 'Potentialcancel', 'Potentialadvice', 'Potentialother' and 'PotentialNA'.

9. Work with RFDS; Rename new_person_id to PID. Convert relevant timestamps from RFDS to AEST and creating MIN/MAX format for: "PTR_Date", "DATETIME_ACTIVATION", "DATETIME_FIRST_CONTACT", "DATETIME_DEPART_WITH_PATIENT", "DATETIME_HANDOVER", "DATETIME_AFR_LEG_ARRIVE", "DATETIME_AFR_LEG_DEPART". Create new vector with dd/mm/yyyy hh:mm datetime attributes. Create new min/max vectors in datetime format. Remove all NA.

10. Bring together converted first PTR date and new_person_id to create a unique ID. Name and save as 'cID' for combined ID. Then, cbind cID, PID, and other related RFDS timestamps to form a new vector, 'RF1'.

11. Identify non-unique cID's. Create new check vector, 'chk'.

12. Create new vector when RF1 is duplicated, Name and save as 'DuplicatedRF1'. And also a vector when RF1 is unique, name and save as, 'RF2'.

13. Review duplicate RFDS cases. Document findings. Create new vector with these removed cases. Name and save as 'C3'.

14. Begin with QNETS: Rename new_person_id to PID. Convert date and time of request and activation date and time to Australian Eastern Standard Time (AEST). Convert to dd/mm/yyyy hh:mm datetime format.

15. Bring together converted Request datetime and new_person_id to create a unique ID. Name and save as 'cID' for combined ID. Then, cbind cID, PID, RequestDT, ActivationDT to form a new vector, 'Q1'.

16. Identify non-unique cID's. Create new check vector, 'chk'.

17. Create new vector when Q1 is duplicated, Name and save as 'DuplicatedQ1'. And also a vector when QI is unique, name and save as, 'Q2'.

18. Review duplicate QNETS cases. Document findings. Create new vector with these removed cases. Name and save as 'Q4'.

19. Follow same steps for episodes with cancellations based on NA in Retrieval date and also in 'TransportType' attribute == "CANCELLED", "ADVICE", "OTHER" or "NA". Name and save as; 'Potentialcancel', 'Potentialadvice', 'Potentialother' and 'PotentialNA'. 20. Begin with LRM: Rename new_person_id to PID. Convert all date and time timestamps to Australian Eastern Standard Time (AEST). Convert to dd/mm/yyyy hh:mm datetime format.

21. Bring together converted Activation datetime and new_person_id to create a unique ID. Name and save as 'cID' for combined ID. Then, cbind cID, PID, DT timestamps; LRMTEAM_ACTIVATED_DATETIME, LRMREADY_TO_DEPART_DATETIME, LRM_DEPART_WITH_MEDICAL_TEAM_DATETIME, LRM_LAND_AT_DESTINATION_DATETIME, LRM_AT_SCENE_PATIENT_DATETIME, LRM_DEPARTURE_READY_DATETIME, LRM_ACTUAL_TIME_DEPART_DATETIME, LRM_ARRIVE_AT_RECEIVING_HOSPITAL_DATETIME, LRM_DEPART_RECEIVING_HOSPITAL_DATETIME, LRM_AVAILABLE_FOR_NEXT_TASKING_DATETIME and date; LRMDate_RETRIEVAL_REQUESTED, LRM_DATE_ARRIVE_BACK_AT_BASE to form a new vector, 'L1'.

22. Identify non-unique cID's. Create new check vector, 'chk'.

23. Create new vector when L1 is duplicated, Name and save as 'DuplicatedL1'. And also a vector when LI is unique, name and save as, 'L2'.

24. Review duplicate LRM cases. Document findings. Create new vector with these removed cases. Name and save as 'L4'.

25. Create a vector with unique PID's for CCRIS, QNETS, LRM and RFDS. Name and save as, 'allPID'.

26. Begin with ED: Rename new_person_id to PID. Convert date and time stamps to Australian Eastern Standard Time (AEST). Convert to dd/mm/yyyy hh:mm datetime format.

27. Bring together converted Arrival datetime and new_person_id to create a unique ID. Name and save as 'cID' for combined ID. Then, cbind cID, PID, TriageDT, StartDT, EndDT, DepartDT to form a new vector, 'ED1'.

28. Identify non-unique cID's. Create new check vector, 'chk'.

29. Create new vector when ED1 is duplicated, Name and save as 'DuplicatedED1'. And also a vector when EDI is unique, name and save as, 'ED2'.

30. Review duplicate ED cases. Document findings. Create new vector with these removed cases. Name and save as 'ED4'.

31. Begin with QHAPDC: Rename new_person_id to PID. Convert date and time stamps to Australian Eastern Standard Time (AEST). Convert to dd/mm/yyyy hh:mm datetime format.

32. Bring together converted Start datetime and new_person_id to create a unique ID. Name and save as 'cID' for combined ID. Then, cbind cID, PID, EndDT to form a new vector, 'QH1'.

33. Identify non-unique cID's. Create new check vector, 'chk'.

34. Create new vector when QH1 is duplicated, Name and save as 'DuplicatedQH1'. And also a vector when QHI is unique, name and save as, 'QH2'.

35. Review duplicate QH cases. Document findings. Create new vector with these removed cases. Name and save as 'QH4'.

36. Begin with Death: Rename new_person_id to PID. Convert date and time stamps to Australian Eastern Standard Time (AEST). Convert to dd/mm/yyyy date format.

37. Bring together converted death date and new_person_id to create a unique ID. Name and save as ‘cID’ for combined ID. Then, cbind cID, PID, deathdate to form a new vector, ‘D1’.

38. Identify non-unique cID’s. Create new check vector, ‘chk’.

39. Create new vector when D1 is duplicated, Name and save as ‘DuplicatedD1’. And also a vector when DI is unique, name and save as, ‘D2’.

40. Review duplicate Dcases. Document findings. Create new vector with these removed cases. Name and save as ‘D4’.

41. Create a new vector that Smartbind CCRIS, QNETS, LRM, RFDS, ED, QHAPDC and death. Sort on PID and cID.

42. Create one .RData folder which contain: CCRIS, QNETS, LRM, RFDS, ED, QHAPDC and death. Name: identify that it’s a linked file, e.g., ‘Linked1.RData’

43. Name and save R code, ‘Linking.R’.

44. Download .RData file and save as a .csv file to OneDrive

Verify Absence of Errors in Datetime

Steps to verify datetime absence of errors.

1. Check individual files to ensure that there are no errors in datetime conversions.

2. Begin with RFDS: Create a new vector to subset one ID# in new_person_id from newS4 and timestamps. Name and save as, ‘check.1’.

3. Create a new vector to subset same # from linked1 and select timestamps. Name and save as, ‘check.2’.

4. Create a new vector to compare these two vectors for mismatches. Name and save documented findings.

Combine similar attributes, determine attribute order & function, attribute reliability and identify missing values

Steps to identify similar attributes, determine attribute order & function, attribute reliability and identify missing values.

1. Determine similar attributes and consistent semantics. Document attribute, source, value and location in df. Name and save, 'Combined.attribute.table.doc'.

2. Read in 'linked1.RData. cbind age in CCRIS, QNETS, EDIS and QHAPDC. Mutate and coalese into a new vector. Verify format and structure.

3. Create a new vector and rename to 'myage'. Add new vector in df. Name and save code.

4. Recode sex as factor: Female==1, Male==2, Unknown==9. cbind sex in CCRIS, QNETS, EDIS and QHAPDC. Mutate and coalese into a new vector. Verify format and structure.

5. Create a new vector and rename to 'mysex'. Add new vector in df.

6. Determine attribute order. Align the most critical linkage attributes to the left-leading side. The sequence started with primary key, data source, request datetime, activation datetime, first contact datetime, at scene datetime, AFR datetime, arrive at receiving facility datetime, handover datetime, sending facility name, receiving facility name, sending locality, and receiving locality.

7. Determine attribute value reliability. Document communicate regarding, RSQ 'Retrieval Date' and EDIS 'arrival_mode' in episodes that aeromedical patients arrive from tarmac in ground transport; errors without indication of a fixed wing or rotor wing transport.

8. Determine attributes to remove in the dataframe. Examine if NULL, NA and blank are the same meaning for missing values. Document attributes with NULL, NA and blank and percentages of each. Document missing values percentages in the dataframe**.** Remove attributes with >90% missing values. Document findings.

9. Create one .RData folder which contain: CCRIS, QNETS, LRM, RFDS, ED, QHAPDC and death. Name: identify that it's a corrected, linked file, e.g., 'Linked1b.RData'

10. Name and save R code, 'Linked1b.R'.

11. Download .RData file and save as a .csv file to OneDrive

Aeromedical entity source and relationships

Steps to identify aeromedical entity source and relationships.

1. Open 'Linked1b.csv'. Visualizing how these entities in relate in spreadsheets will be beneficial.

2. Copy CCRIS, QNETS, LRM and RFDS in 4 sheets. Add episode numbers per PID.

3. Copy/paste first 50 episodes for each in new sheet.

4. Use only PID and timestamps, remove the rest.

5. Combine and sort on PID, then by first, then second timestamp in each source. RFDS activation, then RFDS first contact, QNETS Request datetime, QNETS activation, LRM Retrieval requested, LRM activated, CCRIS request DT, CCRIS date of retrieval.

6. Create new tab with CCRIS, RFDS and LRM. Column A episode number, column B PID, then align timestamps according to timeline CCRIS Request DT, RFDS Activation, LRM activation, RFDS DepartDT, LRM DepartDT, RFDS At scene, LRMwith patient, RFDShandover. CCRIS Retrieval Date. Create Min(C2:T2)/Max (C2:T2) columns. Create timediff column between Min/Max.

7. Do the same with QNETS and LRM. And QNETS and RFDS

Verify aeromedical flattening for overlaps in sending/receiving facility and start/end time

Steps to verify aeromedical flattening for overlaps in sending/receiving facility and start/end time.

1. Prepare RStudio. Required R packages were installed and libraries were loaded; reshape, dplyr, plyr, data.table, stringi, lubridate, readr, ggplot2, stringr, openxlsx. Set working directory. Set option stringsAsFactors=F.

2. Read in, 'LinkedRSQ.xlsx' and individual aeromedical data CCRIS, QNETS, LRM and RFDS.

Determine combined aeromedical, ED, hospital and death entity source and relationships

Steps to determine combined aeromedical, ED, hospital and death entity source and relationships.

1. Prepare RStudio. Required R packages were installed and libraries were loaded; reshape, dplyr, plyr, data.table, stringi, lubridate, readr, ggplot2, stringr, openxlsx. Set working directory. Set option stringsAsFactors=F.

2. Load, 'LinkedRSQ.xlsx'

Appendix C. Qualitative research participant information sheet

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Kristin Edwards
College of Medical, Veterinary and Public Health
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Research Participant Information Sheet

Project Title: Perceptions and experiences of health care providers in rural and remote Central Queensland hospitals when aeromedical transport is requested for patients with suspected appendicitis.

Project Summary:

To explore the perceptions of health care providers when presented with a patient with suspected appendicitis for whom a request of aeromedical transfer to specialised care centre. The study seeks to understand the knowledge, skills and attitudes of rural and remote clinicians during an interhospital patient transfer. This insight into the experiences of the healthcare professional and service may bring about more understanding of the rural health context. Analysis of the findings has potential to better understand the emergency service experiences in rural and remote Central Queensland hospitals.

When?

21st JUNE Wednesday 7:30am – 4:30pm

Where will the interviews be conducted?

We will be conducting interviews in an ED meeting room at [redacted] or over the phone, if you are unable to come to the hospital due to weather or schedule conflicts. Interviews will be recorded and transcribed.

What will I be asked to do?

You will be asked open-ended questions regarding your experiences when you care for patients with suspected appendicitis and they need to be flown to a hospital with specialised services. We will ask about your role in patient care, about your level of experience, education and training. We will also ask about your thoughts and feelings on the challenges or supports in requesting aeromedical transfer in this specific clinical scenario.

How much of my time will I need to give?

We anticipate that the entire interview will take 10 - 25 minutes.

What specific benefits will I receive for participating?

There aren't any direct benefits for your participation; but an opportunity to share your experiences.

Will the study involve any discomfort for me? If so, what will you do to rectify it?

We do not anticipate any discomfort in answering these questions. In the event that you need assistance, OPTUM, a Queensland Health Employee Assistance Service is available 24 hours/ 7 days a week for free and confidential counselling.

Do you intend to publish the results?

Yes, we hope that the results will be published in a peer-reviewed journal that focuses on rural and remote emergency health services.

Can I withdraw from the study?

Participation is entirely voluntary and you are not obliged to be involved. If you do participate, you can withdraw at any time without giving a reason. If you do choose to withdraw, any information that you have supplied will be removed from our data analysis and destroyed via a secure and approved manner.

Can I tell other people about the study?

Yes, you can tell other people about the study by providing them with the chief investigator's contact details. They can contact the chief investigator to discuss their participation in the research project and obtain an information sheet.

Data storage

All data will be stored securely in a locked file cabinet in a locked JCU office of Richard Franklin for 3 years and it will be de-identified.

Appendix D. Permissions

Human research ethics committee approval for qualitative interviews

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Human research ethics committee approval for data linkage

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Public health act approval for data linkage

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Appendix E. Diagnosis chapters

ICD-10-AM diagnosis chapters I-XXII

ICD-10-AM tenth revision Diagnosis Chapters I-XXII

- **ICD-10 Version:2019**
  - I Certain infectious and parasitic diseases
  - II Neoplasms
  - III Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism
  - IV Endocrine, nutritional and metabolic diseases
  - V Mental and behavioural disorders
  - VI Diseases of the nervous system
  - VII Diseases of the eye and adnexa
  - VIII Diseases of the ear and mastoid process
  - IX Diseases of the circulatory system
  - X Diseases of the respiratory system
  - XI Diseases of the digestive system
  - XII Diseases of the skin and subcutaneous tissue
  - XIII Diseases of the musculoskeletal system and connective tissue
  - XIV Diseases of the genitourinary system
  - XV Pregnancy, childbirth and the puerperium
  - XVI Certain conditions originating in the perinatal period
  - XVII Congenital malformations, deformations and chromosomal abnormalities
  - XVIII Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified
  - XIX Injury, poisoning and certain other consequences of external causes
  - XX External causes of morbidity and mortality
  - XXI Factors influencing health status and contact with health services
  - XXII Codes for special purposes

AR-DRG version 7.0 major diagnostic categories (MDC)

Separation statistics by AR–DRG (version 7.0), Australia, 2013–14 to 2014–15
Applied filters: None

Year

MDC

Pre MDC
MDC 01 Diseases and Disorders of the Nervous System
MDC 02 Diseases and Disorders of the Eye
MDC 03 Diseases and Disorders of the Ear, Nose, Mouth and Throat
MDC 04 Diseases and Disorders of the Respiratory System
MDC 05 Diseases and Disorders of the Circulatory System
MDC 06 Diseases and Disorders of the Digestive System
MDC 07 Diseases and Disorders of the Hepatobiliary System and Pancreas
MDC 08 Diseases and Disorders of the Musculoskeletal System and Connective Tissue
MDC 09 Diseases and Disorders of the Skin, Subcutaneous Tissue and Breast
MDC 10 Endocrine, Nutritional and Metabolic Diseases and Disorders
MDC 11 Diseases and Disorders of the Kidney and Urinary Tract
MDC 12 Diseases and Disorders of the Male Reproductive System
MDC 13 Diseases and Disorders of the Female Reproductive System
MDC 14 Pregnancy, Childbirth and the Puerperium
MDC 15 Newborns and Other Neonates
MDC 16 Diseases and Disorders of the Blood and Blood Forming Organs and Immunological Disorders
MDC 17 Neoplastic Disorders (Haematological and Solid Neoplasms)
MDC 18 Infectious and Parasitic Diseases
MDC 19 Mental Diseases and Disorders
MDC 20 Alcohol/Drug Use and Alcohol/Drug Induced Organic Mental Disorders
MDC 21 Injuries, Poisoning and Toxic Effects of Drugs
MDC 22 Burns
MDC 23 Factors Influencing Health Status and Other Contacts with Health Services
Error and Other DRGs

Source: AIHW National Hospital Morbidity Database