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Fresh Perspectives on Hospital-Acquired Neonatal Skin Injury Period Prevalence From a Multicenter Study

Length of Stay, Acuity, and Incomplete Course of Antenatal Steroids

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ABSTRACT

The objective of this study was to explore neonatal skin injury period prevalence, classification, and risk factors. Skin injury period prevalence over 9 months and χ^2, Mann-Whitney *U*, and independent-samples *t* tests compared injured and noninjured neonates, with *P* values less than .05 considered statistically significant. Injury prediction models were developed using Classification and Regression Tree (CART) analysis for the entire cohort and separately for those classified as high or low acuity. The study took place in 3 Australian and New Zealand units. Neonates enrolled ($N = 501$) had a mean birth gestational age of 33.48 ± 4.61 weeks and weight of 2138.81 ± 998.92 g. Of the 501 enrolled neonates, 206 sustained skin injuries (41.1%), resulting in 391 injuries to the feet (16.4%; $n = 64$), cheek (12.5%; $n = 49$), and nose (11.3%; $n = 44$). Medical devices were directly associated with 61.4% ($n = 240$) of injuries; of these medical devices, 50.0% ($n = 120$) were unable to be repositioned and remained in a fixed position for treatment duration. The strongest predictor of skin injury was birth gestation of 30 weeks or less, followed by length of stay of more than 12 days, and birth weight of less than 1255 g. Prediction for injury based on illness acuity identified neonates less than 30 weeks' gestation and length of stay more than 39 days were at a greater risk (high acuity), as well as neonates less than 33 weeks' gestation and length of stay of more than 9 days (low acuity). More than 40% of hospitalized neonates acquired skin injury, of which the majority skin injuries were associated with medical devices required to sustain life. Increased neonatal clinician education and improved skin injury frameworks, informed by neonatal epidemiological data, are vital for the development of effective prevention strategies.

Key Words: epidemiology, friction, neonatal, pressure, shear, skin injury, stripping

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Neonatal skin injuries from mechanical force are currently associated with prematurity and birth weight (BW).[1] Skin injuries as a complication were first identified in the 1980s and described as scars associated with prematurity, which suggests an unpreventable complication of premature birth.[2] Current evidence indicates that injuries are associated with premature skin physiology and a combination of mechanical forces related to lifesaving care.[1,3,4]

Current skin injury models and frameworks that incorporate etiology with prevention appear to be based on adult epidemiological data. Specifically, assessment tools such as the Neonatal Skin Risk Assessment Scale[5,6] and the Braden Q Scale[7,8] were fashioned from adult models but verified by neonatal data, rather than large-scale epidemiological investigations of neonates who sustained injuries. In addition, models that once predominantly focused on pressure injuries are broadening to include skin injury formation from any combination of mechanical forces and medical devices.[9,10] This is important as neonates are at risk for device-related injury associated specifically with respiratory support equipment, medical adhesives, and vascular catheters.[4,9,11–14] Therefore, there is a need for studies to identify risk factors for neonates as the foundation for the development of a measure of risk and assessment specifically for neonates.

Recent reviews have identified that neonatal skin injury frequency ranges from 9.3% to 43.1%.[1] This wide variation could be due to differing study methodologies, making comparison of contributing factors for injury formation challenging.[1] Despite an unknown benchmark for injury frequency, governing organizations and healthcare facilities have an expectation that facility-acquired skin complications are a never event.[15] Further complicating these expectations, neonatal skin injury assessment is reported as complex, with gaps in skin care training for neonatal clinicians.[4,9] Thus, there is an urgent need to better understand the possible direct (extrinsic/modifiable) and indirect (intrinsic/nonmodifiable) causes of skin injuries in neonates to minimize and/or prevent injuries from occurring.[16]

We hypothesized that the prevalence of skin injuries is currently underreported in neonatal units. The objective of this study was to explore the period prevalence, classification, and risk factors of neonatal skin injuries.

METHODS

The Neonatal Skin Injury and Pressure Injury Risk Assessment (NIPIRA) study was an exploratory mixed-methods study of neonatal skin injuries and the epidemiological factors related to pressure, friction, shear, and stripping. The study took place in Australia and New Zealand. Qualitative methods were used to collect data about contextual and social constructs, clinicians' experiences with neonatal skin injuries, and quantitative methods that included observational and photographic data. Only the observational data are reported here.

Setting and location

The 3 participating neonatal units represent both metropolitan and regional tertiary neonatal care facilities. Each unit provides complex care, ventilation, retrieval services, and long-term nutritional and developmental care.[17]

Design

The period prevalence was conducted at each unit over 9 months in 2016 and 2017. *Inclusion criteria*: Neonates born less than 42 weeks' gestation, primary admission to a participating unit, and informed consent obtained anytime postadmission or up to 24 hours after an injury were identified (due to availably of parents to provide consent). *Exclusion criteria*: (i) Injuries unrelated to mechanical force such as surgical wounds, thermal/chemical burns, extravasation from peripheral/central catheters; (ii) injuries obtained during birth (eg, scalp trauma); (iii) inherited conditions (eg, epidermolysis bullosa or myelomeningocele); and (iv) atopic dermatitis, staphylococcal scalded skin syndrome, hemangiomas, and other skin lesions (eg, milia, erythema toxicum). Neonates who did not sustain injuries comprised a control group for statistical analysis of injury risk factors. All neonates were followed until time of discharge or separation from the unit.

Sample size

At the time of calculating the sample size, the minimum injury rate for neonates was unknown; thus, the adult pressure injury rate of 7.0%[18,19] was used to calculate the minimum parameter. The upper parameter was calculated on a neonatal injury rate of 32.0% obtained from retrospective data.[12] On the basis of the one-sample portion test (Wald z),[20] 150 neonates from each site were needed to provide a valid number of injuries with a power of 80% and an α of .05.

Outcomes and variables

Primary outcomes of skin injury acquired from a single or combination of mechanical forces (pressure, friction, shear, and/or stripping) were defined in accordance with the National Pressure Ulcer Advisory Panel (NPUAP) classifications including stages I-IV, deep tissue, and unstageable injuries.[21] For epidermal stripping and skin tear injuries, definitions corresponded with those by Lund[22] and August et al.[23]

Variables for gestational age (GA) in weeks, BW,[11] method of birth, and antenatal steroid courses[24] were categorized on the basis of definitions from the Australian and New Zealand Neonatal Network (ANZNN)

Data Dictionary 2017.[25] The following variables were defined for the context of this research: length of stay (LOS) (number of days hospitalized),[11] plurality (singleton, multiple birth), inborn (born at one of the tertiary hospitals participating in the study), outborn (born elsewhere) (born en route to hospital, at home, or at another hospital not part of the study site, and a nontertiary delivery of care), separation from unit (discharged home, transferred to another unit, deceased, or remained inpatient at study end), and cot humidification (use of cot humidification inclusive of neonates born <32 weeks' gestation as per site guidelines).

Medical devices associated with injury were grouped into 3 categories: (i) *fixed*—device-associated force that cannot be offloaded and force is likely to remain in that anatomical position for the duration of that treatment (eg, endotracheal tube or intercostal catheter); (ii) *adjusted or loosened*—devices that could be adjusted or loosened intermittently, so the mechanical force is temporality offloaded but is likely to remain for the duration of that treatment (eg, continuous positive airway interfaces or phototherapy goggles); or (iii) *movable*—devices that could be relocated or rotated during treatment and/or monitoring (eg, saturation or temperature probe).

The American Academy of Pediatrics/American College of Gynecologists infant acuity levels were used to measure neonatal illness severity.[26] Using the 5-point care level for monitoring, treatments, and interventions, neonates were grouped as *low acuity*—continuing care/intermediate care (level 1 or 2) or *high acuity*—intensive care/multisystem support/unstable requiring complex critical care (levels 3-5).

Data collection

To improve validity of data collection processes, clinicians were educated concerning (i) eligibility criteria; (ii) neonatal skin injury classifications and staging; (iii) requirement and use of the metric and color graduated tape measure[27] (patent no. 2019900648); (iv) injury identification and assessment and using the iPad camera and photographing the injuries; and (v) data input using the iPad Apple Operating system (iOs) application (WoundMap, MobileHealthWare)[28] including use of drop-down menus and free-text boxes. Additional resources available to clinicians included PowerPoint presentations with voice-over instruction available on desktop computers, lanyard cards, and posters with definitions and injury classification images, and step-by-step instruction sheets for data input. Clinicians undertook data collection as part of routine skin inspection in accordance with the Australian Safety and Quality Health Service standards, which require inspection within the admission window and each shift thereafter.[29] Clinicians completed each occasion of data input within approximately 3 minutes.

Anatomical location and injury classification were collected/inputted from application drop-down menus or entry into a free-text box. Due to the nature of the application, classification options were limited to "pressure injury" (any injury caused by mechanical force alone) or "other" (inclusive of 11 preprogramed injury classifications such as "trauma" or "abrasion" or free-text descriptions). On selection of "pressure injury," a further menu opened, prompting selection of injury stages (NPUAP stages).

Data files were cross-checked with the neonate's medical chart and skin injury confirmed for eligibility by the principal investigator (D.L.A.). Missing data were extracted from clinical documents if available. Noneligible injuries were excluded. If there was uncertainty, additional investigators (Y.K., R.R., K.N.) confirmed inclusion or exclusion.

Analysis

Analysis was conducted using SPSS version 22.0 (released 2013; IBM SPSS Statistics for Windows, version 22.0. IBM Corp, Armonk, New York). Descriptive statistics express neonatal demographics and characteristics of injuries. Mean and standard deviation are reported for continuous, normally distributed data and as median and interquartile range (IQR) for continuous, nonnormally distributed data. The Shapiro-Wilk test was used to check normality of the variables. Chi-square, Mann-Whitney U, and independent-samples t tests were used to compare variables for groups of injured and noninjured neonates. A P value less than .05 was considered statistically significant.

Multivariate analysis was conducted using R version 3.3.2 (R Core Team, 2013; R: A language and environment for statistical computing, Vienna, Austria) with the RPART (Recursive Partitioning and Regression Trees) package. Recursive partitioning, called Classification and Regression Tree (CART) analysis, uses variables to separate neonates into different homogeneous risk groups by an algorithm used to determine prediction for injury. This algorithm selects a predictor that provides the best or optimal split so that the subgroups are more alike compared with the outcome (skin injury or no skin injury).[30,31] In contrast to traditional multivariate regression modeling, CART uses the best available information when variables are missing,[32] using similar outcome patterns to determine which side of the split the variable is allocated. This article reports the analysis of primary variables, of which many are unique from previous studies: birth GA, BW, gender, delivery type, inborn/outborn delivery, antenatal steroids, plurality, LOS, illness acuity, and separation from unit.

Secondary analysis of other possible risk factors related to device duration, nutritional factors, and sepsis is ongoing and will be reported elsewhere. CART analysis was conducted 3 times: once for the entire study population and then for the high- and low-acuity groups.

Ethics

This study has received approval from the Townsville Hospital and Health Service Human Research Ethics Committee (HREC/13/QTHS/212), the Royal Brisbane & Women's Human Research Ethics Committee (HREC/16/QRBW/30), Human Research University of Otago New Zealand (H16/099), and the James Cook University Human Research Ethics Committee (H6400). Parental consent was obtained for all participants. All data were collected, stored, and transferred in a secure manner with unique study identification.

RESULTS

During the study period, 1776 neonates met the inclusion criteria, 860 (48%) parents were approached, and 501 (58%) neonates were enrolled. Parents of 29 neonates declined participation, 324 were passive nonrespondents, 6 families had significant language barriers, and there were no withdrawals.

Mean GA was 33.48 ± 4.61 weeks and BW was 2138.81 ± 998.92 g. There were more males (54.9%; $n = 275$) than females (45.1%; $n = 226$). Median LOS was 16.0 (IQR = 8.0-38.2) days. Median time from birth to first injury was 4.08 (IQR = 2.0-9.6) days or 98.0 (IQR = 48.0-231.5) hours. Demographics for the overall population, injured, and noninjured groups are given in Table 1.

Period prevalence

Mechanical force injuries were acquired by 206 neonates (41.1%; $n = 501$). Of the 206 neonates who sustained injury, 109 (52.9% of the injured population) acquired more than 1 injury, with a total of 391 injuries reported (see Table 2). Stage 1 (unblancheable erythema) was reported most frequently (44.0%; $n = 59/134$), followed by epidermal stripping (26.5%; $n = 35/134$), with only a single report of a stage 4 injury and an unstageable injury. Of the 391 injuries, the feet were

Table 1. **Demographics and clinical characteristics of neonates with and without skin injuries**

	All	Without SI	With SI	*P*
N	501	295	206	. . .
Birth GA, mean ± SD	33.46 ± 4.61	35.30 ± 3.60	30.75 ± 4.60	<.001
BW, mean ± SD	2138.81 ± 998.92	2350.00 ± 891.70	1325.9 ± 944.10	<.001
Male, gender, *n* (%)	275 (54.9)	160 (58.2)	115 (41.8)	.725
Female, *n* (%)	226 (45.1)	135 (59.7.8)	91 (40.3)	. . .
Plurality, *n* (%)	. . .	. . .	. . .	.822
Singleton	367 (73.3)	215 (58.6)	152 (41.4)	
Multiple birth	134 (26.7)	80 (59.7)	54 (40.3)	
Birth method, *n* (%)	. . .	. . .	. . .	.441
Spontaneous vaginal delivery	177 (35.3)	100 (56.5)	77 (43.5)	
Cesarean no labor	165 (32.9)	95 (57.6)	70 (42.8)	
Cesarean labor	138 (27.5)	89 (64.5)	49 (35.5)	
Assisted instrument vaginal	21 (4.2)	11 (52.4)	10 (47.6)	
Antenatal steroids, *n* (%)	. . .	. . .	. . .	<.001
Unknown	5 (1.0)	2 (40.0)	3 (60.0)	
None	200 (39.9)	147 (73.5)	53 (26.5)	
<24-h first dose	68 (13.6)	29 (42.6)	39 (57.4)	
Complete (>1 dose)	188 (37.5)	96 (51.1)	92 (48.9)	
Given >7 d before birth	40 (8.0)	21 (52.5)	19 (47.5)	
Inborn, *n* (%)	409 (81.6)	245 (59.9)	164 (40.1)	.328
Outborn, *n* (%)	92 (18.4)	50 (54.3)	42 (45.7)	
Length of stay, median (IQR)	16 (8-38.2)	11 (5-22.5)	37 (15-69)	<.001
Acuity, required ICN, *n* (%)	311 (62.1)	142 (45.7)	169 (54.3)	<.001
Did not require ICN	190 (38)	153 (80.5)	37 (19.5)	<.001
Cot humidity, *n* (%)	111 (22.2)	20 (18.0)	91 (82.0)	<.001
Separation from unit, *n* (%)	. . .	. . .	. . .	.01
Discharge home	249 (49.7)	157 (63.1)	92 (36.9)	
Transfer to another unit	237 (47.3)	136 (57.4)	101 (42.6)	
Deceased	12 (2.4)	1 (8.3)	11 (91.7)	
Study end date before discharge	3 (0.6)	1 (33.3)	2 (66.7)	

Abbreviations: BW, birth weight; GA, gestational age; ICN, intensive care nursery; IQR, inter quartile range (25%-75%); SD, standard deviation; SI, skin injury.

Table 2. **Skin injury frequency**

	n (%)
Total injuries reported, N	391
Mechanical force	134 (34.3)
Stage 1	59 (44.0)
Stage 2	26 (19.4)
Stage 3	3 (2.2)
Stage 4	1 (0.8)
Unstageable	1 (0.8)
Deep tissue injury	9 (6.7)
Epidermal stripping	35 (26.1)
Combination etiology or "other"	257 (65.7)[a]
Anatomical locations	
Feet (including toes)	64 (16.4)
Cheek (face)	49 (12.5)
Nose (septum, bridge)	44 (11.3)
Abdomen	36 (9.2)
Hands (including fingers)	28 (7.2)
Neck	26 (6.6)
Upper limbs (except elbow)	22 (5.6)
Other head (lip, under eye, philtrum)	18 (4.6)
Behind ear (anterior fold)	17 (4.3)
Knees (anterior)	14 (3.6)
Axilla	12 (3.1)
Lower limb (excluding foot and knee)	11 (2.8)
Heel	10 (2.6)
Gluteal (including gluteal fold)	9 (2.3)
Chest	9 (2.3)
Ear (helix, lobe, tragus)	8 (2.0)
Groin	8 (2.0)
Back	3 (0.8)
Elbow	2 (0.5)
Hip	1 (0.3)
Location by tissue structure	
Over long bone (wrist, foot)	192 (49.1)
Soft tissue, ligament (neck, groin)	118 (30.2)
Cartilage (ear, nose)	50 (12.8)
Bony prominence (heel, elbow)	31 (7.9)

[a]The analysis of injuries categorized as "other" in this article is reported in qualitative outputs elsewhere.

Table 3. **Skin injuries association by device type**

	n (%)
Total injuries, *N*	391
Device related	240 (61.4)
Not identifiable, unknown/uncertain	151 (38.6)
Adhesives and securements	*114 (47.5)*
Adhesive standard	71 (29.6)
Saturation probe	29 (12.1)
Adhesive (nonstandard)	3 (1.3)
Electrocardiogram leads	9 (3.8)
Endotracheal tube fixation device	1 (0.4)
Stoma appliance/base plate	1 (0.4)
Vascular access devices	*48 (20.0)*
PIVC	28 (11.7)
CVC	1 (0.4)
PIVC hub	9 (3.8)
CVC clamp	3 (1.3)
Intra-arterial line	1 (0.4)
Splint (vascular assess board)	6 (2.5)
Respiratory interface and devices	*45 (18.8)*
CPAP prongs	23 (9.6)
Humidified high-flow prongs	3 (1.3)
Subnasal prongs	1 (0.4)
CPAP mask	11 (4.6)
CPAP attachment (chin strap, hat)	5 (2.1)
Endotracheal tube, pharyngeal tube	2 (0.8)
Other monitoring and care devices	*26 (10.8)*
Temperature probe	10 (4.2)
Noninvasive blood pressure cuff	1 (0.4)
Monitoring cable	1 (0.4)
Saturation/identification poesy (wrap)	4 (1.7)
Identification badge	3 (1.3)
Bed/crib/incubator	1 (0.4)
Nappy	4 (1.7)
Tourniquet	1 (0.4)
Umbilical cord clamp	1 (0.4)
Other invasive catheters and devices	*7 (2.9)*
Ventriculoperitoneal shunt	1 (0.4)
Intercostal catheter	2 (0.8)
Gastric tube (nasal/oral)	4 (1.7)
Device rotation capacity	
Rotation or movable	50 (20.8)
Adjustable or loosen	70 (29.2)
Fixed position for treatment	120 (50.0)

Abbreviations: CPAP, continuous positive airway pressure; CVC, central venous catheter; PIVC, peripheral venous catheter.

injured most frequently (16.4%; $n = 64$), followed by cheek (12.5%; $n = 49$), nose (11.3%; $n = 44$), and abdomen (9.2%; $n = 36$). Only 7.9% of injuries occurred over bony prominences, such as elbow, compared with 49.1% overriding a long bone, such as metatarsals.

Of the 391 injuries, 61.4%, ($n = 240$) were directly associated with a specific medical device. Injuries were most frequently associated with medical adhesives (47.5%; $n = 114$), vascular access devices (20.0%; $n = 48$), and respiratory devices (18.8%; $n = 45$). Furthermore, 50.0% ($n = 120$) of devices were fixed such as endotracheal tubes whereas 29.2% ($n = 70$) could be loosened or adjusted. Movable devices accounted for 20.8% ($n = 50$) of injuries (see Table 3).

Univariate analysis between injured and noninjured neonates showed no difference for gender and place of birth (inborn compared with outborn). The analysis did indicate differences in LOS ($P < .000$), cot humidity ($P < .000$), GA at birth ($P < .000$), BW ($P < .000$), and separation from unit ($P < .01$) based on groups (see Table 1).

Risk factor for skin injury

Based on CART analysis, the most important predictor of skin injury was GA of 30 weeks or less at birth. The next predictors presented in order of strength of prediction included LOS greater than 12 days and BW less than 1255 g. If a neonate was born greater than 1255 g but between 30 + 1 and 39 weeks, the risk is increased (see Figure 1). Decimals within each CART tree box represent the probability of skin injury (eg, .83 = 83%). Decimals on the left, within each box, represent the probability of neonates within a variable group being injury free and decimals on the right represent probability of being injured, with the darker the box, the higher the prediction.

The study population was then divided into high acuity (level ≥3) or low acuity (level ≤2). The strongest predictors of injury for high acuity were birth GA 30 weeks or less, then LOS greater than 39 days, followed by antenatal steroid courses (noncomplete or <24-hour dose). The strongest predictors of injury for low acuity were GA 33 weeks or less, followed by LOS greater than 9 days, then antenatal steroid courses (noncomplete, single dose, or none), then BW 2555 g or less, and, finally, male gender (see Figure 2).

DISCUSSION

To the best of our knowledge, the NIPIRA study is the first of its kind to investigate neonatal skin injuries using a multimethods approach. This article reporting on the observational aspect of the study has demonstrated that medical device–associated injuries are common and injuries are more likely to occur in overriding bone and soft-tissue locations, which differ from reported sites for injury in older populations (ischial tuberosity or sacrum).[21,33] The etiology of adult skin injury is associated with pressure or shear, friction, or moisture over vulnerable tissue along with factors such as immobility, age, diabetes, and malnutrition.[21,33] In addition, our

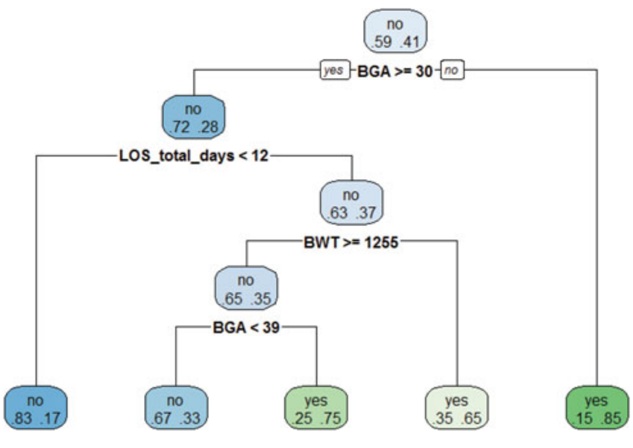

Figure 1. CART analysis of the entire population. BGA indicates birth gestational age (reported in weeks); LOS, length of stay (reported in total days); BWT, birth weight (reported in grams); probability of skin injury (eg, .85 = 85%). This figure is available in color online (www.jpnnjournal.com).

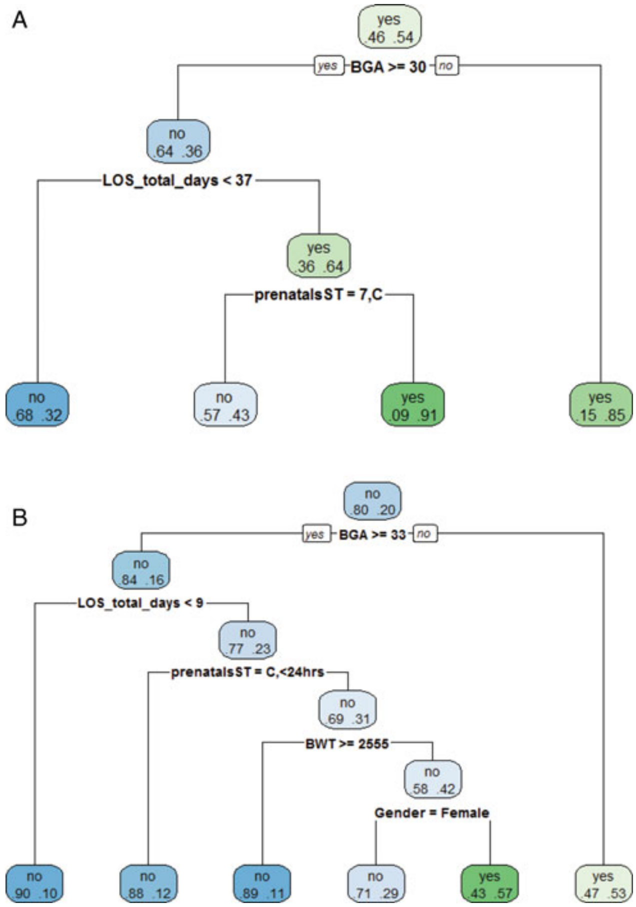

Figure 2. (A) CART analysis acuity level 3 or more. BGA indicates birth gestational age (reported in weeks); LOS, length of stay (reported in total days); prenatal ST, prenatal steroid courses that were complete and/or more than 7 days before birth; probability of skin injury (eg, .85 = 85%). (B) CART analysis acuity level 2 or less. BGA indicates birth gestational age (reported in weeks); LOS, length of stay (reported in total days); prenatal ST, prenatal steroid courses that were incomplete and/or less than 24 hours days before birth); BWT, birth weight (reported in grams); probability of skin injury (eg, .53 = 53%). This figure is available in color online (www.jpnnjournal.com).

results differentiate neonates from older infants who acquire injuries over the occipital bone,[34–36] as we did not find any in our study. Our study has demonstrated that neonates are at risk for skin injury from mechanical forces along with factors such as a birth GA less than 30 weeks, LOS greater 12 days, and fixed medical devices, and initial injuries occur within the first week of life.

Skin injuries associated with medical devices were once considered different to classical pressure injuries despite injury formation involving mechanical forces as well as a device. This study supports the findings of a recent literature review that neonatal skin injury frequency is most often associated with medical devices

(68%-90%),[1] which are extrinsic risk factors as they are assumed to be "modifiable." Of note, respiratory interfaces were attributed to only 18.8% of injuries despite a higher rate of injury (>20%) reported from most studies.[37–39] This finding may reflect an increased awareness of continuous positive airway pressure interface release and/or device rotation due to the adoptions of these practices in many neonatal units.[37,38] Thus, quality improvement activities and care bundles for high-risk neonates are likely to impact on the portion of injuries related to devices that are rotatable (29.2%) and movable (20.8%).[40] However, these results importantly highlight that the greatest proportion neonatal device–associated injuries (50%) were not modifiable or able to be offloaded, and these devices needed to remain in that anatomical position for the duration of that treatment. Thus, the premise of offloading mechanical force to minimize tissue damage, which is the underlying principle for adult skin health, is unlikely to assist in preventing the greatest burden of neonatal skin injuries.[18] Devices that can be only paused, adjusted, or remain fixed will continue to present challenges for clinicians wanting to prevent injuries with current treatment modalities. A future focus on the delivery of care related to specific device types (medical adhesives and vascular assess) or injury locations (feet or cheek) might assist in identifying safer practices for fixed devices. Consequently, these results emphasize the goal of the "never event" for neonatal skin injuries, being unlikely achievement for this hospitalized population with current care practices.

The very nature of fragile premature skin adversely places the neonate at risk for any skin injury despite etiology.[41] Previous studies have suggested that prematurity and lower BW were associated with injury, but our results found that injuries could also occur in neonates slightly older (30.75 ± 4.6 weeks GA at birth) and heavier (1325.9 ± 944.1 g BW).[11] Therefore, the results of this study demonstrate that neonates of all ages including preterm, late preterm, long-term, and neonates requiring high acuity are at risk for injury. While neonatal GA and BW are easily measured, they are not modifiable risks. In addition, GA and BW are not considerations for the number of devices or frequency of device offloading and, in fact, smaller or sicker neonates are likely to have more devices. While past studies have analyzed risk based on GA and BW,[11] our team conducted CART analysis to consider acuity as a practical risk, providing clinicians with insights into which neonates in their care are most at risk for injury based on level of illness.

Given that moisture levels are considered a risk factor for adult acquired skin injuries, the role of ambient moisture was investigated in this study.[42] Consistent with recent research, our study found cot humidification nonpredictive in multivariate analysis despite being found to be significant in univariate analysis.[43] Further research needs to be undertaken to evaluate whether moisture levels have a role in neonatal injuries such as the amount of cot humidification delivered at the exact time of the injury and moisture on the surface of potential skin injury sites.

This study found that noncomplete or less than 24 hours to the first dose of antenatal steroid coverage is a risk factor for skin injury. These results imply that a lack of antenatal steroids may effect lung development and skin health[24,44] or simply indicate overall risk for morbidity including skin injury.[45]

More than half of the neonates in this study had multiple injuries. Further exploration of neonates who acquire multiple injuries compared with those who acquire a singular injury may help identify effective prevention and/or intervention studies. These studies could also investigate injuries where etiology is nonidentifiable or uncertain, a factor not addressed in our study. Most importantly, this study highlights that neonatal skin injury risk factors differ from the ones contained within published and validated risk assessment tools, which place more emphasis on mobility and tissue perfusion and sensory perception. Comparatively, none of the validated tools take into consideration the medical devices, LOS, or acuity. Of the significant risk factors identified within this study, only LOS can be considered extrinsic/modifiable. While GA, BW, and incomplete course of antenatal steroids are all indirect, intrinsic, and nonmodifiable risks associated with being born prematurely. Despite the lack of modifiable risk factors, governing organizations and healthcare facilities will likely continue to consider neonatal skin injuries an avoidable event. Therefore, neonatal clinicians must target prevention campaigns to reduce injuries associated with rotatable and movable devices, with specific attention to prevention during the first week of life for all GAs. The adoption of a standardized neonatal skin integrity and injury assessment within clinical practice will also allow for accurate benchmarking that could contribute toward identifying modifiable risk factors and improved practices for fixed devices. In addition, reduction of injuries associated with fixed devices will likely require collaboration with medical device industry and biomedical engineering to accelerate device innovation.

There are a few limitations to be noted, including the use of clinicians for skin injury assessment. However, the research team provided preparatory education packages including in-services, palm cards, PowerPoint tutorials, and quick guides with images and injury descriptions. Data collected were later verified by researchers who reviewed the clinical images of the injuries. Furthermore, the research team expected some variance in clinical assessments and therefore included image collection of injuries in addition to assessments. These images and the subsequent assessments are under further analysis within another study. While this is the largest investigation of neonatal skin injury in the last 5 years,[11,46,47] not all families were able to be approached about potential participation. Initially, the team envisioned achieving consent from all parents of neonates who met inclusion criteria; however, a number of challenges occurred. Challenges were related to families who remained at referring facilities, unwell mothers, or stressed parents for whom informed consent was considered inappropriate, specific demographics for whom visitation to hospitals is culturally taboo, and parents who chose neither to consent or decline (40%; $n = 324$) but instead remained passive about participation.

CONCLUSION

This study found that 41.1% of hospitalized neonates acquired a skin injury, of which 61.4% of injuries were directly associated with a specific medical device. Such devices are most often required to sustain life and are "fixed" for the duration of treatment. The most important predictors of skin injury were birth GA ($\leq$30 weeks), LOS, and BW ($\leq$1255 g), most of which are nonmodifiable. Increased education for neonatal clinicians and improved neonatal skin injury frameworks, informed by neonatal epidemiological data, are vital for the development of effective prevention strategies.

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