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A value-based approach to prostate cancer image-guidance in a regional radiation therapy centre: a cost-minimisation analysis

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ABSTRACT

Background and objectives: Usual practice for the insertion of prostate fiducial markers involves at least one week delay between insertion and simulation. An evidence-based practice change was implemented whereby fiducial marker insertion occurred on the same day as radiotherapy simulation. The aim of this study was to quantify the health service costs and clinical outcomes associated with this practice change.

Methods: A cost-minimisation analysis was undertaken from the perspective of the local health service. A retrospective chart audit was conducted to collect data on 149 patients in the pre-implementation cohort and 138 patients in the post-implementation cohort. Associated costs with insertion and simulation were calculated and compared across the two cohorts; this included subsided travel costs for rural and remote patients. Fiducial marker positions on planning CT and first treatment CBCT were measured for all patients as the surrogate clinical outcome measure for oedema.

Results: The health service saved an average of AU$ 361 (CI $311 – $412) per patient after the practice change. There was no significant difference in fiducial marker position pre- and post- implementation ($p < 0.05$).

Conclusion: The practice change to perform insertion and radiotherapy simulation on the same day resulted in substantial savings to the health system, without compromising clinical outcomes. The decrease in number of required patient attendances is of real consequence to rural and remote populations. The practice change increases both the value and accessibility of best-practice health care to those most at risk of missing out.

Introduction

Background

External beam radiotherapy (EBRT) is one of the mainstays of prostate cancer treatment. Daily use of image guidance during EBRT reduces the total volume irradiated to a therapeutic dose by minimising the need to compensate for motion of the prostate which in turn reduces treatment related side effects whilst increasing tumour control [1,2]. One image-guidance technique uses radio-opaque fiducial markers inserted into the prostate to serve as a highly visible surrogate for prostate position.

Insertion of fiducial markers (also known as seeds) is well tolerated [3,4]. However, routine practice is to delay treatment planning computed tomography (CT) acquisition for several days or weeks after the insertion [1,4,5]. The rationale for the delay is to lessen the influence of oedema and haemorrhage on seed position, allowing sufficient time for the markers to settle into a relatively fixed position [1,4–8]. The delay was informed primarily by evidence from studies of brachytherapy where 50 to 150 radioactive seeds are inserted into the prostate causing marked prostate oedema [9]. However, only three fiducial markers, each measuring 1.2 mm × 3 mm, are standardly used for image guided radiation therapy, reducing the risk of oedema [4].

When first implementing our department's fiducial marker program in 2010, the one-week delay was adopted as the clinical protocol based on the above evidence available at the time. However, many patients within the local health service region live in rural and remote locations and need to travel considerable distances to access the radiation

Abbreviations: VBHC, Value-based health care.

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oncology services at our hospital. The prospect of travelling to the clinic twice prior to treatment is inconvenient and increases out of pocket costs for the patient. Additionally, it increases the financial burden on the health system due to reimbursement of travel costs via a patient travel subsidy scheme.

Evidence suggests medical oncology patients prefer same day services where possible, quoting distance to appointments and convenience as key reasons [10]. Similarly, patients with prostate cancer and breast cancer indicate a preference for hypo-fractionated schedules to reduce treatment time and burden [11,12]. A geographical access study conducted in the local northern Queensland region showed utilisation of radiation therapy services increased when distance to the service decreased [13].

In response to these issues, a departmental clinical audit retrospective study was initiated to investigate the need for this delay. This study found that fiducial marker insertion associated with oedema was not clinically significant, and thus, the delay between insertion and treatment planning CT was likely to be an unnecessary barrier to efficient, timely and patient-centred access to care [8].

Value-based health care (VBHC) is increasingly recognised as an important consideration in health services. The classic Donabedian VBHC model has been adapted to radiation oncology, with structure (including equipment and technology), processes (including health care interactions and technical delivery of care) and outcomes (including objective measures such as survival, and subjective such as quality of life) [14]. Emphasis is placed on the preferences and outcomes that matter to the patient [14–16]. In radiation oncology, processes which are patient-centred and optimise access, timeliness and care coordination are paramount in achieving value for the patient [14].

In this paper, we present a cost-minimisation analysis to quantify the differences in health service resource use and cost for patients who received same-day insertion and treatment planning CT, as compared with those who experienced a one-week delay. Fiducial marker positions for both groups were estimated as a surrogate measure of clinical outcomes.

Methods

Study design

We adopted a retrospective pre-post study design [17] to compare patients receiving treatment over the two years prior to, and following, the introduction of the practice change to perform same-day fiducial marker insertion and treatment planning CT (Fig. 1). Participants were retrospectively identified from administrative databases as having attended with biopsy proven prostate adenocarcinoma and who elected to undergo radiation therapy with fiducial marker insertion between January 2013 and December 2017. Fiducial marker insertion throughout this period was performed by one of two radiation oncologists trained in this procedure. Low complication rates and no differences in either complications or marker loss between the two radiation oncologists have been demonstrated in a previous departmental audit, with no infection reported in the 127 patients evaluated [18].

Patients were included in the pre-intervention group if they had received treatment prior to the practice change in March 2015 and were included in the post-treatment group if they had received treatment after the service change, up to December 2017. Patients were excluded from the study if less than three markers were present on either scan, or where significant marker migration occurred. Patients who were implanted with markers but did not go on to complete radiation treatment were included within the analysis using an intention to treat approach.

We adopted a health service perspective for the costing analysis. The time horizon for the cost analysis covered the time patients first presented for fiducial marker insertion until their first day of radiation treatment. Institutional ethics approval was obtained prior to data collection, which included a waiver of consent to access retrospective patient data (HREC/QTHS/66293).

The practice change

We have previously published the findings of a study assessing

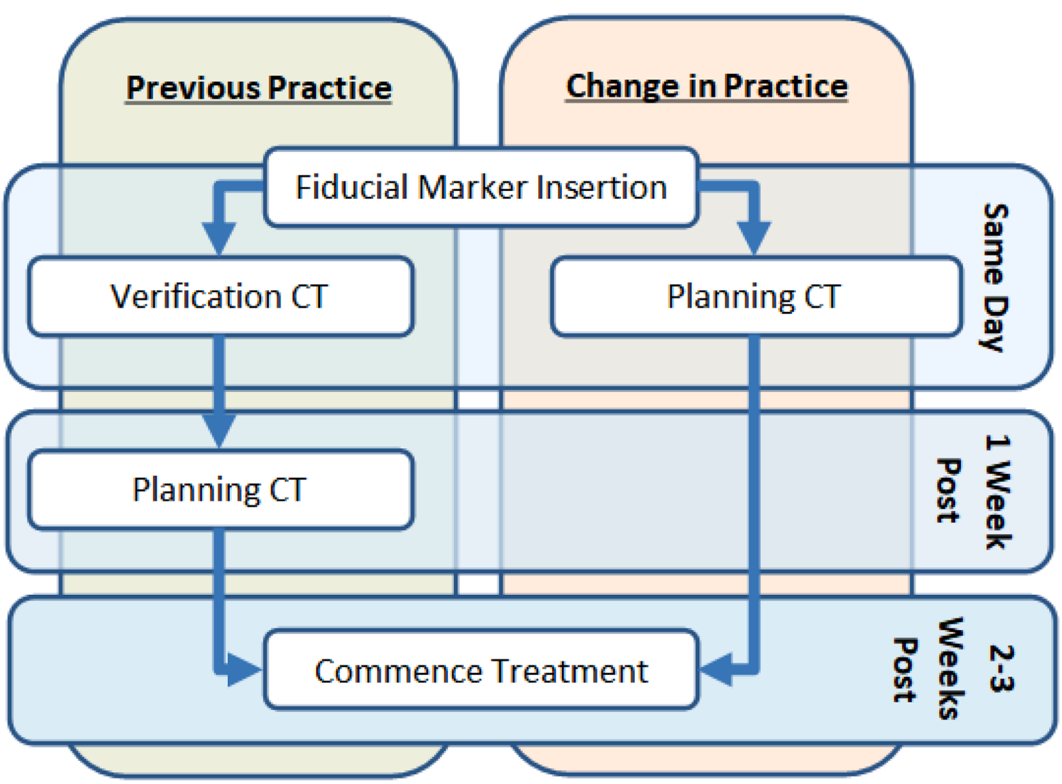

Fig. 1. Representative flowchart of pre- and post-practice change.

oedema induced by fiducial marker insertion at our centre [8]. This study directly assessed prostate volume and inter-marker distances on CT at time of insertion and a week later during treatment planning CT. No significant difference was found in prostate size or shape between the two data sets. Planning target volume expansions were adequate to ensure coverage of the clinical target volume in accordance with the International Commission of Radiation Units and Measurement (ICRU) report 83 [19] and did not require changing from routine departmental practice. Since completion of this study in February 2015, all prostate patients have undergone fiducial marker insertion and treatment planning CT on the same day. Apart from the removal of the one-week delay, key insertion parameters have remained consistent (including number of needle insertions and staff performing insertions).

Setting and participants

This study was conducted at a regional tertiary hospital in Australia, the only tertiary hospital within regional northern Queensland providing public hospital radiation therapy. The hospital's catchment covers 149,500 km^2 and more than 700 000 people [20]. Many patients attending oncology appointments at the hospital need to travel large distances.

Within the public health system of Australia, radiation therapy services are provided at no cost to the patient, covered by the federal universal health care system [21]. The local health service reimburses patients for eligible costs of travel greater than 50 km and accommodation through the state-wide Patient Travel Subsidy Scheme.

Clinical outcomes

The difference between fiducial marker position at time of treatment planning CT and at the time of cone beam CT was adopted as a surrogate measure of prostate oedema for both groups. Individual inter-marker distances were calculated for three marker combinations. Centroid position of fiducial markers was also calculated and subsequently a vector magnitude of the centroid shift between the CT and first treatment position (Fig. 2). The area between the centre of the three markers was also assessed within each group in absence of an updated prostate contour. This methodology combines the practices of earlier studies that relied on 2D measurements from planar films [7,22,23] with more recent publications that utilise 3D datasets to assess volumetric information [5,6,8]. All clinical data were retrospectively collected from hospital databases.

Cost outcomes

All costs are reported in 2021 Australian dollars. Costs of staff time under each model of care were derived using standardised procedure times documented by patient appointments. Pre-procedural preparation and planning was assumed to be consistent across groups for marker insertion. Hourly wage rates plus on-costs from the relevant Queensland Health employment agreements were applied for Radiation Therapists [24], Nurses [25] and Medical Officers [26]. The increment applied to staff based on years of service was averaged across each role to reflect a mid-point. Equipment costs included capital cost of CT scanners attributed over the 10-year useful life of the unit [27,28] as well as estimated power consumption of the unit per pelvic scan [29].

Health service costs associated with patient travel subsidies were estimated using the allowable rates under the Patient Travel Subsidy Scheme. This included an allowance of AU$60 per night spent at commercial accommodation, with car travel calculated at the subsidised rate of AU$0.30 per kilometre from the nearest Queensland Health service provider to the street address of the treating facility. The mode by which patients travelled was extracted from relevant chart notes. Within-group means were used to impute missing data items for 28 pre-intervention and 17 post-intervention participants.

While a subsidised travel allowance is available for patient carers or travel escorts, this was not included due to lack of available data. Additional data on patient out of pocket costs were not available, nor were the administration staff time and costs.

Statistical analysis

Analyses were conducted in Microsoft Excel and R. Differences between demographics of cohorts were calculated through a Student's *t*-test for numerical data or chi-square test for categorical data. Differences in fiducial marker position was analysed with a paired *t*-test comparing the position of the markers on planning CT to first day of treatment marker position. Significance was considered at $p < 0.05$.

Disaggregated costs were summarised using descriptive statistics, with confidence intervals estimated using the percentile method after bootstrapping with 10,000 replications. Given the short time horizon, costs remain undiscounted.

Results

A total of 309 patients met the inclusion criteria. 22 patients were excluded from the analysis; 21 for having only 2 markers present on imaging and 1 for a significant marker migration of several centimetres. Of the remaining patients, 149 patients were included in the pre-intervention group and 138 in the post-intervention group. Within the post-intervention group, 4 patients required recollection of planning data due to clinical decision making such as prolonged hormone therapy or repositioning. As such the time frames of these patients were beyond that of normal workflow. Reflecting an intention to treat approach, they were included in the analysis of both clinical and cost measures with both CT timepoints included.

Table 1 summarises the characteristics of the cohort. No significant differences were observed between the pre- and post-intervention groups with respect to patient age, Gleason score or androgen deprivation therapy. Greater distances to the treating facility from patient postcode, or distances from nearest health facility to the treating facility were noted in the pre-intervention group ($p = 0.047$). Higher stages of diagnosis were observed in the post-group ($p = 0.029$). The median number of days from CT to treatment was 21 and 22 days for the pre- and

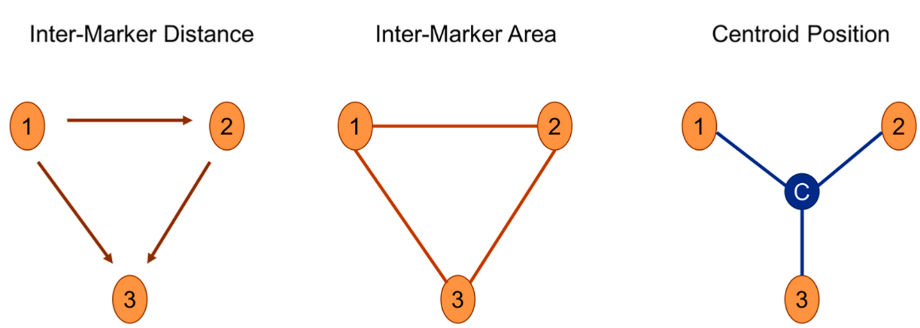

Fig. 2. Depiction of the measures between the three fiducial markers calculated as a surrogate measure of prostate oedema.

Table 1
Patient Demographics.

Measure	Pre-intervention (n = 149)		Post-intervention (n = 138)		p-value
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	
Age (Years)	70.9 (6.90)	*66.2–88.4*	72.1 (7.07)	*67.4–86.7*	*0.157*
Distance from Suburb (kms)	172.18 (201.52)	*9.5–1222.0*	127.73 (176.28)	*7.6–902.0*	*0.047*
Distance from Health Service (kms)	166.19 (204.12)	*0.0–1222.0*	121.04 (180.33)	*0.0–902.0*	*0.048*
Gleason Score	**n**	**%**	**n**	**%**	
6	32	*21*	35	*25*	*0.367*
7	61	*41*	62	*45*	
8	23	*15*	18	*13*	
9	30	*20*	19	*14*	
10	2	*1*	4	*3*	
Not Recorded	1	*1*	–	–	
Stage (TNM)	**n**	**%**	**n**	**%**	
II	118	*79*	90	*65*	*0.029*
III	25	*17*	35	*25*	
IV	6	*4*	13	*9*	
Androgen Deprivation Therapy	**n**	**%**	**n**	**%**	
No	22	*15*	11	*8*	*0.116*
Yes	127	*85*	127	*92*	
	Median	**IQR**	**Median**	**IQR**	
Days from CT to Treatment	21	15–28	22	21–34	*0.245*

SD: Standard Deviation; CT: Computed Tomography; IQR: Interquartile Range; kms: kilometres.

post- groups respectively.

The difference in fiducial marker position was not statistically significant between the pre- and post- groups (Table 2), indicating no difference in oedema outcomes. The vector magnitude between CT and first day was not statistically different, with a mean pre-group magnitude of 0.15 (SD: 0.08) and post-group of 0.15 (SD: 0.10).

The attributable procedure-related costs in the pre- and post- cohorts are detailed in Table 3. Most costs were attributed to staffing, with a small proportion attributable to CT running/on-costs.

Total health service costs, including costs of subsidised travel, are reported in Table 4. The average cost per patient to insert fiducial markers and collect planning data was AU$903 for the pre-intervention group compared with AU$542 in the post-intervention. This resulted in a net health system saving of AU$361 per patient (95 % CI –412; −311).

Discussion

This study calculated health service cost savings from a practice change to perform fiducial marker insertion and treatment planning CT for prostate cancer patients on the same day, as compared with the previous model of care that required a one-week delay [8]. There were no statistically significant differences in fiducial marker position following the practice change, confirming our previous finding that a delayed planning scan is clinically unnecessary. Cost savings attributable to the health service reduced by a mean of AU$361 per patient. These results were robust to the effects of uncertainty, with 95 % confidence intervals that did not cross zero.

While there was a statistically significant difference between the stage of cancer with later stages noted in the post-intervention cohort, this did not impact upon the fiducial marker position. The difference in travel distance between the pre- and post-intervention cohorts is attributable to a new radiotherapy private practice commencing in a nearby city previously within our catchment area.

Prior studies examining fiducial markers and oedema have been limited by sample size [7,8,23]. Governing bodies and advisory groups recommend a minimum of several days between procedures for best standard of care, however this has been historically based on brachytherapy procedures [9], and highlighted the need for the confirmation of no clinical outcome change in a large sample size in this present study. No significant difference for clinical target volume coverage were demonstrated when using departmental planning target volume expansions for 100 patients on a scan collected at time of insertion and 7 days later [5]. Most recently, same-day insertion of both fiducial markers and hydrogel spacer demonstrated the stability of both prostate volume and fiducial marker position when comparing the simulation and verification scans (3–4 weeks later) [30]. Similarly, our previous study comparing the CT data set from day of insertion and 7 days later showed no difference in volume for 20 patients [8], and this is further supported by our current findings. Whilst our departmental workflows allow us to easily schedule the two procedures on the same day, this may not always be feasible given the range of disciplines that insert fiducial markers [1,4].

The use of routinely collected administrative data in estimating health service use provided an objective and complete data source that was not materially affected by missing data or loss to follow up. The pre-post comparison we adopted here is a type of 'quasi-experimental' design using a non-randomised historical control. This type of study design is commonly used in health services research as it can generate evidence faster and at lower cost than experimental studies, which are not always feasible [17]. These studies are well suited to estimating non-health outcomes, including economic consequences, and typically generate evidence with a high degree of external validity [31]. Nonetheless, we recommend that our findings be confirmed in future studies.

There are some limitations of this study to note. This study was conducted at a single regional tertiary hospital servicing a geographically large area. As such, the estimated cost savings may not be generalisable to other settings. An additional limitation is the lack of costs quantifiable from the patient's perspective. The reliance on retrospective review of chart notes meant potentially important costs borne by patients were not captured. This may include direct out-of-pocket costs, and other financial and non-financial impacts such as loss of income, interruption to carer duties, reduced community engagement, inconvenience or stress experienced by patients who were required to travel twice to the hospital prior to starting radiation therapy. We note that 67% of prostate cancer cases occur in men over the Australian retirement age of 65 years which may reduce the impact of loss of income [32].

In the regional Australian context, distance to health care is a legitimate barrier to access of care and can be a determining factor when considering treatment options. Patients serviced by regional health facilities are likely to have limited access to GP and specialist medical care, a greater burden of illness and disability and subsequently shorter lives than their metropolitan counterparts [33]. Efforts should be made to promote accessibility in this group who are at greater risk of the negative impacts of the social determinates of health.

Financial toxicity of prostate cancer treatment is increasingly

Table 2
Fiducial Marker Distance, Area & Centroid Location.

Measure	Pre-intervention			Post-intervention		
	CT	**1st Day**	*p-value*	**CT**	**1st Day**	*p-value*
Mean FM1 - FM2 in cm (SD)	2.5 (0.81)	2.5 (0.81)	*0.961*	2.6 (0.91)	2.6 (0.93)	*0.564*
Mean FM1 - FM3 in cm (SD)	1.8 (0.85)	1.8 (0.85)	*0.912*	1.9 (0.80)	1.9 (0.78)	*0.609*
Mean FM2 - FM3 in cm (SD)	2.2 (0.77)	2.2 (0.77)	*0.859*	2.4 (0.88)	2.3 (0.87)	*0.538*
Mean FM Area in cm^2 (SD)	1.6 (0.80)	1.6 (0.79)	*0.757*	1.9 (0.91)	1.8 (0.93)	*0.491*

FM: Fiducial Marker; SD: Standard Deviation.

Table 3
Costings attributable to Pre- and Post-Intervention Procedures.

Pre-Intervention						
Insertion Procedure						**Sub-total of Cost per procedure ($)**
Process	**RN**	**RT - Senior**	**RT - Junior**	**RO**	**Minutes**	
Hourly Rate ($)	**54.53**	**80.19**	**62.26**	**217.56**	**60**	
Telephone Call			1		5	5.19
Observation	1				10	9.09
Consult				1	15	54.39
Preparation/Education			1		20	20.75
Insertion	1		1	1	30	167.18
Verification CT		1	1		30	71.23
CT On-Cost					30	63.49
Observation	1				10	9.09
PCSN Consult	1				30	27.27
CT Procedure (+7 Days)						
Process						
Prep			1		15	15.57
Consult				1	10	36.26
CT		1	1		30	71.23
CT On-Cost					30	63.49
Nursing	1				30	27.27
Post-Intervention						
Insertion & CT (Same Day)						
Process						**Sub-total of Cost per procedure ($)**
Telephone Call			1		5	5.19
Observation	1				10	9.09
Consult				1	15	54.39
Preparation/Education			1		20	20.75
Insertion	1		1	1	30	167.18
CT/Rescan		1	1		30	71.23
CT On-Cost					30	63.49
Observation	1				10	9.09
PCSN Consult	1				30	27.27

RN: Registered Nurse; RT: Radiation Therapist; RO: Radiation Oncologist; PCN: Prostate Cancer Specialist Nurse; CT: Computed Tomography. *Note: all costs are in AU$.*

Table 4
Differences in costs between pre and post intervention cohorts.

Cost category	Pre-intervention	Post-intervention	Difference	95 % CI of the difference
	Mean (SD)	**Mean (SD)**		
Total Health service costs	**903 (275)**	**542 (150)**	**−361**	**−412 to −311**
Procedure	673 (57)	438 (61)	−235	−249 to −221
Subsidised travel	196 (234)	83 (118)	−113	−157 to −71
Subsidised accommodation	34 (56)	20 (38)	−14	−25 to −3

SD: Standard Deviation; CI: Confidence Interval. *Note: all costs are in AU$.*

reported. The mean total of out-of-pocket costs was AU$9,205 (SD AU $14,567) in a population of 289 Australian men with prostate cancer, while those with private health insurance reported higher out-of-pocket costs [34]. Five percent of respondents reported spending less than AU $250 out of pocket costs for their prostate cancer treatment and 23 % reported retiring sooner than planned after their diagnosis. A more recent study reports out-of-pocket costs for prostate cancer patients without health insurance increased over time (mean AU$1,586 in 2011 compared to AU$4,748 in 2014) [35]. While we could not quantify the patient out-of-pocket costs, we anticipate patient savings due to reduced requirement of visits to the hospital, and even greater saving for patients traveling long distances for treatment. A recent review of telehealth appointments within Queensland, Australia found that decreased travel and reduced time away from usual activities equated to a societal productivity gain of AU$304 per consult regardless of age [36].

Our model of care demonstrates a saving to the health service, with the majority attributable to the reduction of procedures and reimbursement of patient travel. However, radiation oncology departments in other jurisdictions may have different health care reimbursement arrangements. In a health setting where the patient is out-of-pocket for travel costs, this saving would be of importance to the patient rather than the health system. Nevertheless, we have quantified the benefits for the health service by estimating the opportunity cost savings in freeing up further appointment slots.

In recognising our data is specific to our department, we have presented our data and findings with external validity and transferability of economic evaluations in mind [37,38]. The procedural, staffing, overhead and reimbursement costs presented in this manuscript could be extrapolated to the local settings and payer models, noting the differences known in fiducial insertion procedures between departments [1,4].

The new model of care embraces a value-based approach with demonstrated cost savings and equitable outcomes. Escalating costs within radiation oncology are exacerbated by rapidly evolving technologies and increasing wage rates.[39] Of the average AU$361 saved by the health service per patient in the post-intervention group, AU$155 was attributable to staff time and fixed capital on-costs. The reduction in required hospital visits contributes to improved access and affordability for regional and remote populations seeking healthcare [40,41].

The need to provide value-based radiotherapy is well recognised, and the focus of initiatives such as the Health Economics in Radiation Oncology programme of the European Society for Radiotherapy and Oncology (ESTRO-HERO). Work is underway to develop a framework "defining and assessing the value of radiotherapy innovations, to support clinical implementation and equitable access, within a sustainable healthcare system" [42]. There is merit in evaluating current practices for opportunities to enact changes which provide value-based care, benefiting the patient and/or the health system, as we have demonstrated here.

Conclusion

Implanting fiducial markers and simulating prostate cancer patients on the same day resulted in substantial cost savings to the health service. Different reimbursement models in other jurisdictions may alter the cost impact to both the health service and patients. Future work is required to quantify the out-of-pocket cost savings to the patient, as well as other benefits from improved access to care included reduced indirect costs and improved patient experience.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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