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Time-driven activity-based costing of low-dose-rate and high-dose-rate brachytherapy for low-risk prostate cancer

Annette M. Ilg[1,*], Aaron A. Laviana[1], Mitchell Kamrava[2], Darlene Veruttipong[2], Michael Steinberg[2], Sang-June Park[2], Michael A. Burke[3], Douglas Niedzwiecki[4], Patrick A. Kupelian[2], Christopher Saigal[1]

[1]*Department of Urology, Institute of Urologic Oncology, David Geffen School of Medicine at University of California, Los Angeles, CA*
[2]*Department of Radiation Oncolgoy, David Geffen School of Medicine at University of California, Los Angeles, CA*
[3]*Performance Excellence, Los Angeles Health System, University of California, Los Angeles, CA*
[4]*Operative Services, Los Angeles Health System, University of California, Los Angeles, CA*

ABSTRACT

PURPOSE: Cost estimates through traditional hospital accounting systems are often arbitrary and ambiguous. We used time-driven activity-based costing (TDABC) to determine the true cost of low-dose-rate (LDR) and high-dose-rate (HDR) brachytherapy for prostate cancer and demonstrate opportunities for cost containment at an academic referral center.

METHODS AND MATERIALS: We implemented TDABC for patients treated with I-125, preplanned LDR and computed tomography based HDR brachytherapy with two implants from initial consultation through 12-month followup. We constructed detailed process maps for provision of both HDR and LDR. Personnel, space, equipment, and material costs of each step were identified and used to derive capacity cost rates, defined as price per minute. Each capacity cost rate was then multiplied by the relevant process time and products were summed to determine total cost of care.

RESULTS: The calculated cost to deliver HDR was greater than LDR by $2,668.86 ($9,538 vs. $6,869). The first and second HDR treatment day cost $3,999.67 and $3,955.67, whereas LDR was delivered on one treatment day and cost $3,887.55. The greatest overall cost driver for both LDR and HDR was personnel at 65.6% ($4,506.82) and 67.0% ($6,387.27) of the total cost. After personnel costs, disposable materials contributed the second most for LDR ($1,920.66, 28.0%) and for HDR ($2,295.94, 24.0%).

CONCLUSIONS: With TDABC, the true costs to deliver LDR and HDR from the health system perspective were derived. Analysis by physicians and hospital administrators regarding the cost of care afforded redesign opportunities including delivering HDR as one implant. Our work underscores the need to assess clinical outcomes to understand the true difference in value between these modalities. © 2016 American Brachytherapy Society. Published by Elsevier Inc. All rights reserved.

Keywords: Time-driven activity-based costing; Brachytherapy; Value-based care; Prostate neoplasms; Cost analysis

Introduction

Despite controversies regarding the detection and management of prostate cancer, its public health burden remains high. Roughly 80% of new prostate cancer cases are diagnosed at the local stage (1). The cost to payers for providing care for men diagnosed with localized disease is substantial (2).Without a consensus for the optimal treatment of low-risk prostate cancer, management varies tremendously, including active surveillance, brachytherapy, external beam radiation therapy, cryotherapy, and radical prostatectomy (3). In an environment where ‘‘value-based

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* Corresponding author. Department of Emergency Medicine, Harvard Affiliated Emergency Medicine Residency at Beth Israel Deaconess Medical Center, One Deaconess Road, Rosenberg 2, Boston, MA 02215. Tel.: +1-440-670-4200; fax: +1-617-754-2350.

E-mail address: amilg@bidmc.harvard.edu (A.M. Ilg).

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care'' is being championed by both public and private payers (4), the financial risk of providing care may be increasingly placed on providers. Health care ''value'' is generally defined as a state in which efforts are made to improve the ''numerator'' clinical outcomes while reducing the ''denominator'' health care cost. While many provider organizations have developed programs to improve safety, quality of care, and patient-centered outcomes (5), few studies have elucidated the relative cost to deliver prostate cancer treatments from the provider perspective (6).

Among the challenges in understanding provider perspective, cost is a lack of a robust costing methodology. Traditional hospital accounting systems have the capability of measuring operational and support services well but do not accurately measure cost at the patient level (7). Cost-shifting across service lines also renders elements of cost opaque. Given the unsustainable trajectory of costs in the health care system (8), a reliable and transparent method of measuring the cost of hospital-related and physician-related services is needed to help providers manage. Time-driven activity-based costing (TDABC) is a recent innovation in costing methodology that allows hospitals and providers to systematically track the cost of a disease across the entire process (9). This methodology accounts for personnel, space, and equipment costs measured as a capacity cost rate (CCR; cost per minute). CCR is defined as the institutional CCR, or the amount used per minute, for every resource involved in the process maps. The CCR is then applied to the average time a patient spends with each resource. Material costs are included as the base cost per disposable resource used.

Low-dose-rate and high-dose-rate (LDR vs. HDR) brachytherapy without external beam radiation therapy and androgen deprivation therapy are two approaches with significantly different care processes. We outlined I-125, preplanned LDR, and computed tomography (CT) based HDR brachytherapy with two fractions delivered through two separate implants. We hypothesized that TDABC was a feasible way to describe provider perspective cost using each form of brachytherapy. We also hypothesized that targets for cost reduction could then be identified, potentially reducing cost in each approach.

Methods and materials

Background and overview

To determine the provider-perspective cost of LDR and HDR, we incorporated the TDABC method as originally described by Kaplan and Anderson at the Harvard Business School (9). Through this methodology, the path of a patient across an episode of care for LDR and HDR was detailed through process maps (Fig. 1). Next, resources used including personnel, space, equipment, and materials were incorporated into each step. All costs associated with purchasing and maintaining these resources were obtained (e.g., for personnel: salary, fringe benefits, and support resources). The time that each resource was available to treat patients was then calculated. With each cost and availability, the CCR was calculated by dividing the total costs of supplying that resource by its available capacity for productive work. Subsequently, the process time or average

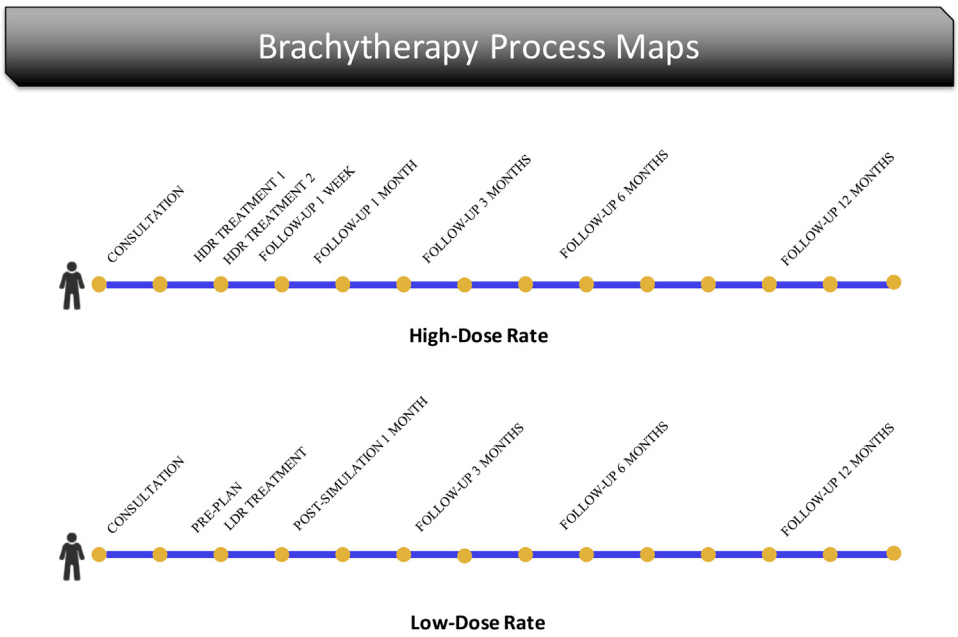

Fig. 1. Macroscopic view of the process map for high-dose-rate and low-dose-rate brachytherapy identifying the major steps involved in treating localized, low-risk prostate cancer from initial consultation through 12 months of follow-up after the intervention.

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time, a resource was used during the episode of care was determined. Finally, the overall cost of the episode of care, from initial consultation through 12 months of radiation oncology followup was calculated as the summation of the process times multiplied by the CCRs.

Defining the process map

To define a full cycle of care for LDR and HDR, we first outlined the steps of care with brachytherapy experts at our institution. Next, direct observation in real time was performed across the entire episode of care for seven patients to better understand the minute detail involved at our institution (Fig. 2). The working process maps were then presented to and verified by key personnel involved. This included radiation oncology attendings and residents, urology attendings and residents, a physicist, and brachytherapy nurses, radiation therapists, and dosimetrists. Subsequently, we assembled a team of clinicians, business analysts, clinical administrators, operative administrators, and nurse supervisors to review the data and verify the clinical and administrative processes used, as previously described (9, 10). Here, we defined the episode of care for both LDR and HDR brachytherapy as initial radiation oncology consultation to intervention through 12 months radiation oncology followup.

Similarly, timing estimates were first supplied by experts and then measured through real-time samples. These estimates were then verified with key personnel performing each step. In addition, we captured timing data from 90 patients treated with CT-based HDR brachytherapy between May 2014 and February 2015 and equipment capacity data based on 1,151 HDR treatments performed from January 2010 through December 2014. HDR for low-risk prostate cancer was defined here as two treatment days with two separate implants with one fraction delivered through each implant. Experts from Vanderbilt University who currently perform preplanned LDR and experts at University California, Los Angeles (UCLA) who previously performed LDR were consulted to verify process-level timing. Patient records, operative reports, and anesthesia records from six patients treated with LDR brachytherapy at UCLA between July 2010 and June 2012 were analyzed for further verification of process times.

In addition to process timing, the probability that a process step would occur was obtained and applied across the care episode, for example, brachytherapy nurses report only a 5% likelihood a patient will require a Foley catheter following discharge after LDR or HDR for inability to void spontaneously. The likelihood each step would take place is accounted for such that the cost of each step is only included as often as that respective step occurs.

Beyond the process steps, timing, and probabilities, we identified the cost of every resource involved in treatment: space, personnel, and equipment and materials as well as the average time a patient spends with each resource.

Space

Across the episode of care for HDR and LDR, 24 different spaces were used including waiting rooms, examination rooms, procedure rooms, operating rooms (ORs), inpatient rooms, work rooms, supply rooms, restrooms, and hallways. Each of these spaces were identified through direct observation and verified with key personnel. Blueprints of each floor and department encountered during the episode of care were obtained from the manager of the Space Inventory Services at UCLA. The blueprints were subsequently analyzed for exact square footage per room and verified by on-site measurements. Space costs obtained from operative services at UCLA included new construction costs per square foot, useful life years, annual construction depreciation and maintenance, annual

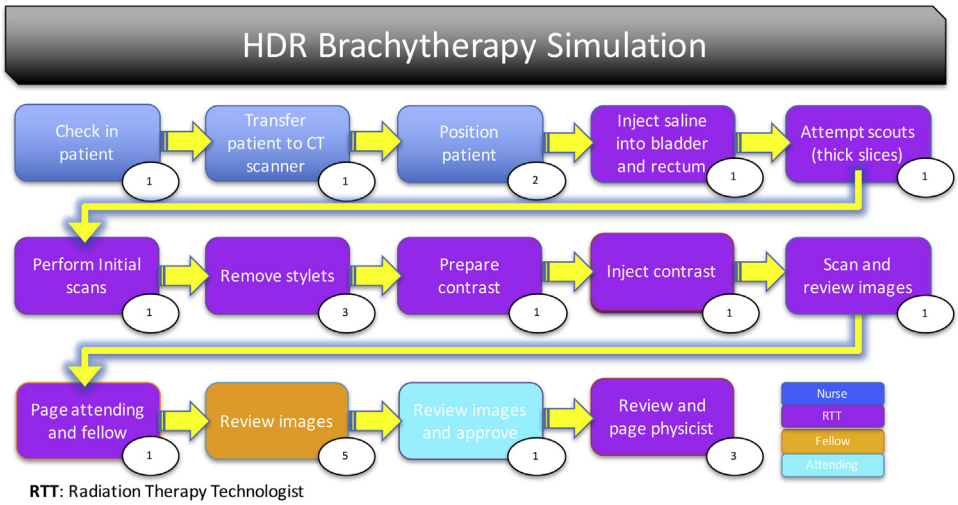

Fig. 2. Step-by-step process map of all clinical and administrative steps involved in the simulation phase of high-dose-rate brachytherapy. The median time for each step is shown in the circles. CT, computed tomography; RTT, radiation therapy technologist.

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operating costs including utilities, yearly housekeeping costs, real estate value, and real estate life years.

Personnel

Personnel involved were initially outlined by experts in the field then elaborated on through direct observation. During the episode of care, 36 personnel were identified including call center representatives, administrative assistants, preoperative and postoperative nurses, brachytherapy nurses, brachytherapy radiation therapists, dosimetrists, physicists, fellows, radiation oncology attendings, anesthesiologists, and urological surgeons. Cost data were obtained from the chief financial officer including salary, bonuses, benefits, supervision, assistant or administrative support, training and travel, office space, hardware support, office expenses, and malpractice insurance. All salaries were based on our institutional data, which is publically available.

Equipment and materials

Vital radiation oncology equipment was first detailed by experts in the department and again elaborated on direct observation. All equipment was photographed and cataloged to calculate cost. Detailed master lists from the UCLA clinical engineering, materials management, supply processing distribution department, OR equipment account specialist, procurement and strategic sourcing department, radiation oncology clinic manager, main OR supply department, surgery center supply center, pharmacy business office, and radiation oncology department orders were all obtained to identify the base cost for each piece of equipment used. In addition, equipment and materials were identified as reusable equipment vs. disposable materials. Material costs were detailed down to the cost of surgical gowns, sterile gloves, and scrub caps used during the episode of care. Equipment costs included service contracts for both LDR and HDR treatment planning systems as well as quality assurance costs. Equipment and material costs were further detailed by cost of depreciation, maintenance and repair, and utilities.

Availability

We estimated the available capacity for each resource for productive work, measured in minutes. For personnel, we used the entire calendar year and subtracted the time unavailable for each person due to vacations, holidays, breaks, weekends, and continuing education. For example, urology attending surgeons were estimated to work 10.5 hours per day, including work from home and had an estimated personnel capacity of 137,469 minutes (11).

CCR and price per unit of the resource

To calculate the CCR per resource, we used the total cost for each space, personnel, equipment, and materials to comprise the numerator of the equation. The denominator accounts for the availability of each resource. Therefore, the CCR is the amount used per minute, of each resource (materials: e.g., price per minute of the Iodine-125 permanent seeds; personnel: e.g., salary per minute of a dosimetrist during treatment planning; space: e.g., cost per minute for the OR) involved in the process maps.

Total cost

To calculate the total cost of caring for an average patient over a complete cycle of care for each intervention, we multiplied the total time spent on each resource at a process step by its CCR. The products were then summed and added to the cost of disposable instruments. The summation of the process steps in each treatment algorithm resulted in the total cost for each intervention. We then compared the price of LDR to HDR brachytherapy and determined the relative price differences. The institutional review board deemed this study exempt from review.

Results

The calculated cost to deliver HDR brachytherapy was greater than LDR brachytherapy by $2,669 ($9,538 vs. $6,869). The first and second HDR treatment day cost $4,000 and $3,956 (Table 1), respectively, while LDR was delivered on one treatment day and cost $3,888 (Table 2). The overall cost of HDR and LDR varied considerably due to the number of treatments delivered. The data used to estimate multifraction HDR was analyzed and compared with hypothetical single-fraction HDR as an area of substantial interest. Single-fraction treatment was estimated at a cost of $5,582. As expected, single-fraction is markedly cheaper than the cost of multifraction therapy, and more notably, is less costly than LDR.

Table 1
HDR monotherapy cost per process step

HDR process step	Cost ($)	Relative cost (%)
Consultation	983.48	10.3
HDR treatment 1	3999.67	41.9
HDR treatment 2	3955.67	41.5
Followup 1 week	70.42	0.7
Followup 1 month	110.52	1.2
Followup 3 months	133.65	1.4
Followup 6 months	133.65	1.4
Followup 12 months	133.65	1.4
Quality assurance (QA)		
Daily QA per patient	10.04	0.1
Monthly QA per patient	5.02	0.1
Quarterly QA per patient	0.67	0.0
Annual QA per patient	1.26	0.0
Total cost	9537.71	100.0

HDR = high-dose rate.

The cost breakdown for HDR monotherapy for each process step and the respective relative cost.

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Table 2
LDR monotherapy cost per process step

LDR process step	Cost ($)	Relative cost (%)
Consultation	983.48	14.3
Preplan	987.85	14.4
LDR treatment	3887.55	56.6
Postsimulation 1 month	595.67	8.7
Followup 3 months	133.65	1.9
Followup 6 months	133.65	1.9
Followup 12 months	133.65	1.9
Quality assurance (QA)		
Annual QA per patient	13.34	0.2
Total Cost	6868.85	100.0

LDR = low-dose rate.

The cost breakdown for LDR monotherapy for each process step and the respective relative cost.

An unpaired *t*-test was conducted to compare operative time for LDR and HDR. There was a statistically significant difference for LDR vs. HDR (99.5 ± 18.6 minutes, $n = 6$ vs. 150.7 ± 26.8 minutes, n = 90, $p < 0.0001$). These results demonstrate that LDR operative times comprise only 33.0% of the total operative time for HDR (99.5 vs. 150.7 minutes per treatment) but 64.0% of the intraoperative cost ($3,625 vs. $5,664). The HDR treatment days vary by $44 ($2,854 and $2,810) due to the cost of the platinum fiducial marker seeds placed only during the first implant.

During the operative period, personnel costs for HDR and LDR were similar at $1,804 and $1,768, respectively. Both procedures are performed with a circulating nurse, anesthesiology attending, radiation oncology fellow, radiation oncology attending, surgical technician, and urological surgeon. LDR in addition requires a physicist to be present during the operative portion, which contributes to the similar personnel costs amidst the shorter operative times.

Intraoperative materials for HDR implants 1 and 2 cost $970 and $926, respectively, while materials for LDR cost $1,781 resulting in a difference of $855 per treatment. The Iodine-125 permanent seeds contributed 81.5% of the cost of disposable materials during the operative period at $1,451 while the Best Medical International Flexi Needles (Springfield, VA) used for HDR implants 1 and 2 comprised 47.4% and 49.7% of the cost of disposable materials during the operative period at $459.79 for each treatment. The contributions of resources to the intraoperative cost for LDR and HDR treatment are displayed in Tables 3 and 4.

Although operative costs are higher for LDR, the overall treatment for HDR and LDR result in similar cost due to the additional steps in the process map for the HDR treatment day. After the Flexi-Needles are placed, the patient recovers in the postoperative anesthesia care unit before undergoing simulation, treatment planning, treatment delivery, and finally recovery. After leaving the OR, these process steps contribute an additional $965 to the total cost of the treatment day for HDR while patients receiving LDR recover in the postoperative anesthesia care unit and are discharged home without a catheter 95.0% of the time.

Table 3
LDR monotherapy intraoperative cost

Resource	Cost ($)	Relative cost (%)
Personnel	1,768.20	48.77
Anesthesia	395.37	
Circulating Nurse	126.91	
Fellow	79.01	
Surgical Technician	61.80	
Radiation Oncology Attending	611.14	
Urology Attending	245.97	
Physicist	236.19	
Hospital Assistant (quantity−2)	11.81	
Space	30.43	0.84
Operating Room	29.19	
Preoperative Room	1.24	
Equipment	45.35	1.25
Varian Medical Systems	5.14	
STORZ Cystoscope	1.86	
STORZ Camera	7.47	
BK Medical Ultrasound	16.39	
OR table	8.53	
Stryker Neptune Waste Management	1.02	
Materials	1,781.37	49.14
I-125 permanent seeds	1,451.00	
Sequential Compression Device Set	65.97	
Sterile surgical gowns (quantity−6)	17.29	
Sterile surgical gloves (quantity−6)	9.42	
Surgical masks (quantity−6)	4.16	
Nine inch foam donut	11.39	
Eggcrate foam pad (quantity−2)	2.88	
Bair hugger	8.14	
Stirrup strap with slip ring (quantity−2)	7.93	
Iothalamate Meg 60/50 mL vial	10.56	
Check-Flo Adapter 9F	9.82	
22-French Foley Catheter	8.05	
18-French Council Tip Foley Catheter	12.92	
Urine drainage bag 2000 mL	3.62	
Ultrasound probe drape	7.22	
Total cost	3625.36	100.0

LDR = low-dose rate.

The cost breakdown and respective relative cost for the intraoperative process step for LDR. Equipment and material cost breakdown includes major contributors only.

Overall, the greatest cost driver for both LDR and HDR was personnel at 65.6% ($4,507) and 67.0% ($6,387) of the total cost, respectively. After personnel costs, disposable materials contributed second most at $1,921 (28.0%) for LDR vs. $2,295 (24.0%) for HDR.

Discussion

Quality of care, patient satisfaction, and patient safety have become a focus for many providers and health systems, yet cost containment has received markedly less attention (12). However, federal and private payors are increasingly focused on methods to contain health care costs while maintaining population health. To that end, current costing methodologies remain somewhat opaque and arbitrary, challenging cost containment measures. Our

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Table 4
HDR monotherapy intraoperative cost

Resource	Cost ($)	Relative cost (%)
Personnel	1,803.56	60.73
Anesthesia	603.48	
Circulating Nurse	195.07	
Fellow	117.35	
Surgical Technician	77.59	
Radiation Oncology Attending	602.03	
Urology Attending	196.23	
Hospital Assistant (quantity - 2)	11.81	
Space	35.24	1.19
Operating Room	33.99	
Preoperative Room	1.24	
Equipment	73.92	2.49
STORZ Cystoscope	2.11	
STORZ Camera	8.48	
BK Medical Ultrasound	18.60	
OR table	9.68	
Stryker Neptune Waste Management	1.16	
Materials	1,057.01	35.59
Flexi Needles	459.78	
Platinum Fiducial Marker Seeds	44.00	
Sequential Compression Device Set	65.97	
Sterile surgical gowns (quantity - 6)	17.29	
Sterile surgical gloves (quantity - 6)	9.42	
Surgical masks (quantity - 6)	4.16	
9 inch foam donut	11.39	
Eggcrate foam pad (quantity - 2)	2.88	
Bair hugger	8.14	
Stirrup strap with slip ring (quantity −2)	7.93	
Iothalamate Meg 60/50 mL vial	10.56	
Check-Flo Adapter 9F	9.82	
22-French Foley Catheter	8.05	
18-French Council Tip Foley Catheter	12.92	
Urine drainage bag 2000 mL	3.62	
Ultrasound probe drape	7.22	
Total cost	2,969.73	100.0

HDR = high-dose rate.

The cost breakdown and respective relative cost for the intraoperative process step for HDR. Equipment and material cost breakdown includes major contributors only.

study illustrates that TDABC holds promise as a way to identify cost containment measures and has several significant findings.

First, TDABC is a feasible method to document provider cost (13–15). This costing methodology itself uses considerable personnel time to directly observe patients throughout the care process (16, 17). We were able to achieve our results using students and trainees who were interested in expanding their understanding of health services methods. Materials, equipment, personnel, and space used during the care process were assessed and integrated into detailed process maps created by this front-line team, working under the supervision of content experts. Subsequently, these maps were presented to key personnel and subject matter experts for review and verification. Ultimately, key personnel and experts developed investment in the overall project while their respective volunteered time was minimized (18). Although novices to the TDABC method experience a learning curve that can be time intensive, after creating the first model, investigators quickly become facile in the methodology allowing widespread implementation intradepartmentally (14) as well as over multiple service lines (17). Initial description of unit costs can be leveraged across other efforts. For example, similar personnel, space, equipment, and materials were used for LDR as HDR allowing cost analysis to be completed in a fraction of the time compared with HDR. Moreover, the process maps detailed here may serve as a template for other institutions in potential reform opportunities using our algorithms to analyze how to best streamline care.

Second, HDR is more expensive to deliver than LDR at $9,538 compared with $6,869. This difference can primarily be ascribed to the additional treatment day for HDR and longer operative times at 150.7 compared with 99.5 minutes. Interestingly, the cost for each individual treatment day for HDR and LDR are similar and vary by only $112. However, the additional treatment day for HDR in total adds $3,956 to the cost. Overall, the greatest cost driver comprising over 60% of the cost for each treatment modality is personnel at $4,507 for LDR and $6,387 for HDR. Thus, longer operative times lend to higher overall cost.

Third, analysis by physicians and hospital administrators of the cost of care attributed to each step afforded redesign opportunities (19) including the implementation of HDR monotherapy as one implant with either one or two fractions as well as moving toward ultrasound-based rather than CT-based planning. Modifying the care process of HDR from two implants on separate treatment days to one implant minimizes operative times and thus personnel costs. This adaptation has the potential to eliminate the difference in cost between HDR and LDR.

Fourth, our data document provider-perspective costs, which may be useful to inform cost effectiveness analyses regarding prostate cancer treatment that aim to take the perspective of an entity managing population health. Most work in this area employs costing methodologies based on Medicare reimbursements involving common procedural terminology codes. Previous studies estimate the cost of brachytherapy to be lower than radical prostatectomy and external beam radiation therapy; however, these reports estimate the cost of either LDR alone or generalize brachytherapy without differentiating between HDR and LDR (20–24). Cost estimates in these studies did not include purchasing equipment, materials, performing quality assurance, or maintenance fees; although one recent study has included these details and illustrated TDABC for LDR. Thaker et al. (25) demonstrated high intraoperative costs and preoperative planning magnetic resonance imaging at 41% and 10% of the total cost of the full cycle of care, respectively. Although LDR was studied, HDR has yet to be characterized. We believe that our data may be useful in producing more robust cost effectiveness analyses, though they must account for local variations in costs of delivering care.

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When analyzing our study, the limitations of its design must be considered. First, our cost estimates represent care at a tertiary academic medical center where teaching is an integral component. Operative times with residents may thus be longer and caution should be exercised when extrapolating this cost to private and community centers (26, 27).Second, real-time ultrasound planning was not analyzed as it is not currently being used at our center but could be measured in future studies as it becomes more common (28).Third, we confined our study to low-risk disease and the costs of providing care to men with higher risk disease will likely vary, given the use of combined treatment and hormonal deprivation that attends these risk strata. Fourth, our study had a limited sample size for LDR as our institution has primarily converted to HDR. In addition, none of the LDR was taken back to the OR to optimize their implant, and thus, this potential cost, though infrequent, was not modeled. Fifth, as a provider-perspective analysis, our methodology does not include direct or indirect cost to the patient for the intervention and treatment of side effects. Sixth, our study defines the denominator of the value-based care equation but does not address the numerator, patient-centered outcomes.

Our next step is to understand the overall value. While we have outlined cost, we need to better define relative outcomes of care. Previous observational studies have shown no difference in biochemical control or cause-specific survival between HDR, LDR, and intensity modulated radiation therapy (IMRT) (29–32). Beyond biochemical recurrence, HDR has been associated with less side effects including a statistically significant difference in the rate of dysuria, urinary frequency, and rectal pain (31). Therefore, although biochemical recurrence rate at 5 years has been demonstrated to be similar, the quality of life aspects associated with these side effects should be weighed against the potential cost savings for LDR.

The transformation to value-based health care has begun. The Cleveland Clinic has shown marked improvements in outcomes, efficiency, and growth in market share (7), and Thaker et al. (25) identified nonvalue added steps to guide process improvements and theorize potential bundled payment models. As accountable care organizations and bundled payment programs are integrated into US health care, the true cost of care for entire disease processes will be needed to optimize value in health care delivery (5, 10, 12). Our work underscores the need to assess whether there is any difference in outcomes between LDR and HDR including quality of life, biochemical recurrence, and patient satisfaction.

Conclusions

The TDABC methodology creates a framework that allows investigators to become facile at estimating health care cost from the provider perspective. This allows health care systems to better understand resource utilization, associated cost, and areas of inefficiency. As cost containment increasingly becomes the responsibility of the provider and health care redesign emphasizes value-based care, the demand for true and transparent cost will rise. We present TDABC data for HDR and LDR for localized, low-risk prostate cancer from initial consultation through 12 months of radiation oncology followup. Our results demonstrate a difference in cost with HDR estimated to be $2,669 more expensive than LDR. We found that HDR was more costly due to the additional treatment day and longer operative times. Overall, TDABC is a feasible and powerful costing methodology that can propel value-based care redesign.

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