A comparative study using time-driven activity-based costing in single-fraction breast high-dose rate brachytherapy: An integrated brachytherapy suite vs. decentralized workflow

Gabriella C. Squeo¹, Courtney M. Lattimore¹, Nicole L. Simone², Greg Suralik³, Sunil W. Dutta³, Michael D. Schad³, Lucy Su³, Bruce Libby³, Einsley-Marie Janowski³, Shayna L. Showalter⁴, Jennifer M. Lobo⁴, Timothy N. Showalter³,∗

¹Division of Breast and Melanoma Surgery, Department of Surgery, University of Virginia School of Medicine, Charlottesville, VA
²Department of Radiation Oncology, Sidney Kimmel Cancer Center at Thomas Jefferson University, Philadelphia, PA
³Department of Radiation Oncology, University of Virginia School of Medicine, Charlottesville, VA
⁴Department of Public Health Sciences, University of Virginia School of Medicine, Charlottesville, VA

ABSTRACT

INTRODUCTION: Precision breast intraoperative radiation therapy (PB-IORT) is a novel approach to adjuvant radiation therapy for early-stage breast cancer performed as part of a phase II clinical trial at two institutions. One institution performs the entire procedure in an integrated brachytherapy suite which contains a CT-on-rails imaging unit and full anesthesia capabilities. At the other, breast conserving surgery and radiation therapy take place in two separate locations. Here, we utilize time-driven activity-based costing (TDABC) to compare these two models for the delivery of PB-IORT.

METHODS: Process maps were created to describe each step required to deliver PB-IORT at each institution, including personnel, equipment, and supplies. Time investment was estimated for each step. The capacity cost rate was determined for each resource, and total costs of care were then calculated by multiplying the capacity cost rates by the time estimate for the process step and adding any additional product costs.

RESULTS: PB-IORT costs less to deliver at a distributed facility, as is more commonly available, than an integrated brachytherapy suite ($3,262.22 vs. $3,996.01). The largest source of costs in both settings ($2,400) was consumable supplies, including the brachytherapy balloon applicator. The difference in costs for the two facility types was driven by personnel costs ($1,263.41 vs. $764.89). In the integrated facility, increased time required by radiation oncology nursing and the anesthesia attending translated to the greatest increases in cost. Equipment costs were also slightly higher in the integrated suite setting ($332.60 vs. $97.33).

CONCLUSIONS: The overall cost of care is higher when utilizing an integrated brachytherapy suite to deliver PB-IORT. This was primarily driven by additional personnel costs from nursing and anesthesia, although the greatest cost of delivery in both settings was the disposable brachytherapy applicator. These differences in cost must be balanced against the potential impact on patient experience with these approaches. © 2021 The Authors. Published by Elsevier Inc. on behalf of American Brachytherapy Society. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Keywords: Intraoperative radiation therapy; Breast cancer; Time-driven activity-based costing; High dose-rate brachytherapy; Integrated brachytherapy suite; Ct-on-rails
Introduction

Healthcare costs in the United States are continuously rising, with a significant portion of the country’s expenditure going towards cancer care (1). The national cost associated with cancer is expected to increase by 34% between 2015 and 2030, for an overall expenditure totaling $246 billion (2). When considering all cancer care services and prescription drugs, female breast cancer costs are the highest among other types of cancers (2). In an effort to combat these rising costs, emphasis has been placed on value-based cancer care; value is the measure of positive outcomes achieved per dollar expended for a patient (3). This is in contrast to a payment model solely determined by the individual cost of services received. In radiation oncology, the idea of incorporating value into clinical decision-making and factoring it into payment models has been considered a way to help reduce cancer costs while increasing benefit to the patient (4). Clinicians are encouraged to follow guideline-concordant care, which has been shown to reduce overall costs, use of healthcare resources, and even reduce mortality in cancer patients, thus creating a balance in developing the most effective yet inexpensive course of treatment for each individual patient (5).

Time-driven activity-based costing (TDABC) is a cost-analysis technique that can be used to evaluate the cost of a given medical treatment. This approach follows a formalized, step-by-step process to track the personnel, equipment, and facilities costs associated with treatment in order to provide an estimate overall cost (6). TDABC has been used at our institution within the radiation oncology department to investigate the costs associated with radiation therapy options for prostate, uterine, and cervical cancers (7–9). Most recently, we have utilized TDABC to compare a novel form of intraoperative radiation therapy (IORT) using CT-guided high-dose-rate (HDR) brachytherapy with conventional breast IORT (CB-IORT) for early-stage breast cancer (10).

IORT is a form of accelerated partial breast irradiation for early-stage breast cancer that delivers the entirety of a planned high-dose radiation course at the time of breast-conserving surgery (BCS). Our institution developed precision breast IORT (PB-IORT), which is currently being studied in Phase II, multicenter clinical trial (NCT02400658; R01CA214594–02). Our novel method utilizes HDR brachytherapy techniques to deliver a form of IORT with computed tomography (CT) image guidance, customized CT-based treatment planning, and an iodine-192 HDR source to deliver a higher and more conformal radiation dose when compared to CB-IORT (12.5 Gy to 1 cm depth vs. 5–7 Gy to 1 cm depth in CB-IORT) (11,12). At the core of PB-IORT is the utilization of image guidance, which has been shown to detect clinically significant, correctable, issues in up to 25% of cases (13,14).

The potential merits of image guidance must be balanced against the delivery costs, which is influenced by facility and technical factors. At our institution, we utilize a brachytherapy suite with an integrated CT-on-rails unit which allows for all stages of treatment to be performed in the same room, rapidly, without moving the patient (15). Conversely, our partner institution provides similar care distributed across multiple locations, utilizing an ambulatory operating room (OR) that is separate from the brachytherapy suite to deliver same-day care. This allows for the unique opportunity to directly compare these two different facility models for the delivery of PB-IORT. In this study, we apply TDABC to evaluate delivery costs of in-room imaging versus a decentralized, distributed workflow when performing HDR brachytherapy-based breast IORT.

Methods and materials

Clinical management

This study represents clinical care that is delivered through an ongoing Phase II, multicenter clinical trial of PB-IORT (NCT02400658). The clinical trial was approved by the institutional review board (IRB #18,004) and informed consent was obtained from all participants. Inclusion criteria for PB-IORT were patients who were at least 45 years old, had invasive or in situ carcinoma, a tumor size ≤ 3 cm, and were pathologically node-negative (N0). All patients with invasive cancers underwent sentinel lymph node biopsy before, or at the time of, their IORT. Exclusion criteria included patients with a history of ipsilateral breast cancer treated with radiation, lymph node involvement, BRCA gene mutation, breast implants, and treatment with neoadjuvant chemotherapy.

A complete description of the treatment protocol has been published previously (11). At the University of Virginia, the entire treatment process occurs in a brachytherapy suite consisting of an OR table with a CT-compatible insert, a CT-on-rails imaging unit, an HDR afterloader, and full anesthesia capabilities (15). After BCS is performed, a multi-lumen balloon brachytherapy applicator (Contura; Hologic, Inc., Bedford, MA) is placed in the surgical cavity and secured in place by the breast surgeon. A CT scan is then immediately performed using the CT-on-rails system in the integrated brachytherapy suite (Siemens Somatom; Siemens Healthcare, Erlangen, Germany). Catheter placement is confirmed, and the applicator position is adjusted accordingly. Radiation treatment planning software (BrachyVision v13.6; Varian Medical Systems; Palo Alto, CA) is then used to contour target volumes and organs at risk and to plan treatment. Once the treatment plan is approved and safety checks are completed, HDR brachytherapy treatment is delivered in a single, 12.5 Gy fraction to the planning target volume via an HDR afterloader (Varian Varisource iX HDR afterloader; Varian Medical Systems). After radiation treatment is complete, the brachytherapy applicator is removed, the cavity is inspected, local tissue
Fig. 1. Process map in an integrated brachytherapy suite to deliver single-fraction, high dose-brachytherapy delivered at time of breast conserving surgery for early stage breast cancer. This process includes surgery and intraoperative radiation therapy occurring within a single episode of care with the patient under anesthesia. CT = computed tomography; HDR = high dose-rate; IORT = intraoperative radiation therapy; OAR = organs-at-risk; OR = operating room; QA = quality assurance; UVA = University of Virginia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

transfer is performed if necessary to achieve satisfactory cosmesis, and the incision is closed by the surgeon. All of these steps occur with the patient anesthetized under the care of a trained anesthetist. The radiation oncologist is present for contouring, radiation treatment planning, and delivery of HDR brachytherapy.

Conversely, at Thomas Jefferson University, the steps required to perform PB-IORT are distributed across different locations. Such a configuration of facilities and equipment for radiation therapy represents facility characteristics that are found commonly at hospitals in the United States. The patient undergoes BCS and multi-lumen balloon brachytherapy applicator (Contura; Hologic, Inc., Bedford, MA) placement at an outpatient surgical center. After the patients recovers, she is discharged from the surgical center later that day. The patient then reports to the radiation oncology department (approximately 2 blocks away), where a CT scan is performed. Minor adjustments may be made to applicator positioning at that time, although this is limited by the absence of an OR environment and surgeon. Treatment planning, delivery, and applicator removal all occur in the radiation oncology department. Once the entire procedure is complete, the patient is discharged home. For the purposes of cost estimates, we
assumed the same equipment specifications for CT simulator, brachytherapy treatment planning, and HDR afterloader systems.

**Time-driven activity-based costing**

Process maps were created for each institution, the University of Virginia (Fig. 1) and Thomas Jefferson University (Fig. 2), to represent all treatment steps involved in delivering PB-IORT at each institution. The specific resources involved in each step were identified by observation and input from staff. Capacity cost rates for each resource were calculated by dividing the annual costs by total annual capacity for the resource. Equipment and facility costs were determined by the administrative department with a 10-year time horizon for equipment (and annual service contract included). Annual personnel costs were calculated from institutional salary and fringe benefit data from a single institution to account for different salaries at different institutions. Time per step was estimated through staff member interview and observation, and, therefore, estimates are meant to represent an approximate average per
case. Personnel time attributable to IORT was included, while time spent performing other activities were excluded. For example, it was assumed that surgeons were able to perform other administrative and clinical tasks while waiting for radiation treatment planning and delivery. The time estimates for attending and resident surgeons represent the typical times per case to position and remove the applicator, and as such may not capture personnel costs associated with rare cases that require exceptional repositioning efforts. The additional time required of the anesthesia staff was included in the cost analysis, as they are required to be present during the entire procedure at the University of Virginia, and are unable to cross-cover other responsibilities. Based on the capacity of personnel, equipment and facilities, we assumed capacity for four IORT cases per day at both facilities. We then calculated total costs of care by multiplying the capacity cost rates by the time estimate for the process step and adding any additional product costs.

Results

HDR brachytherapy-based PB-IORT costs less to provide ($3262.22) at a distributed facility with care occurring across multiple distinct locations, compared to delivery in an integrated brachytherapy suite with in-room imaging ($3996.01) (Table 1). The difference in costs for the two facility types was driven primarily by personnel costs, attributable to higher costs for nursing and anesthesia staff with an integrated suite ($1263.41) compared to a distributed facility ($764.89). Equipment costs were slightly higher with an integrated suite than a distributed facility ($332.60 vs. $97.33). A summary of primary equipment costs for HDR brachytherapy-based IORT are shown in Supplementary Table 1.

Consumable supplies represent the largest source of costs ($2400), which is the same at both facility types (Table 1). Personnel time and costs were the second highest contributor to overall delivery costs. A breakdown of each personnel’s time spent per case and costs are shown in Table 2 for each facility type. Total personnel time in an integrated setting was 575 min and 290 min in a distributed setting. In the integrated facility, more time was required by the radiation oncology nurse (132 min vs. 20 min), physicist (134 min vs. 119 min), anesthesia resident, anesthesia attending, and scrub nurse (each 66 min vs. 10 min) when compared to the distributed setting. Increased time required by these personnel translated to increased costs per case in an integrated facility: radiation oncology nurse ($147.84 vs. $22.40), physicist ($361.80 vs. $321.30), anesthesia resident ($42.90 vs. $6.50), anesthesia attending ($281.16 vs. $42.60), and scrub nurse ($72.92 vs. $11.20). The personnel time and cost per case were the same for the radiation oncology attending, attending surgeon, surgery resident, and radiation oncology therapist at both facility types. Radiation oncology nursing and anesthesia attendings represented the greatest cost differences between an integrated suite and standard facility. Additional information regarding model assumptions, equipment and components of capacity cost rates calculation estimates are shown in Supplementary Table 2.

Discussion

The overall cost of care is higher when utilizing an integrated brachytherapy suite ($3996.01) to deliver PB-IORT compared to a decentralized model with the more common distributed facility characteristics ($3262.22). The additional personnel costs from nursing and anesthesia staff were the primary drivers of the higher delivery costs in an integrated brachytherapy suite, with a smaller effect from the costs of equipment. The greatest single category of delivery costs was the disposable brachytherapy balloon ap-
plicator, suggesting a clear opportunity to reduce costs with a different applicator. Our findings suggest that hospitals may deliver PB-IORT at a lower cost in a distributed facility, with a separate OR and brachytherapy suite, compared to an integrated brachytherapy suite with in-room imaging and intraoperative delivery at the same time as BCS. However, the delivery cost difference must be balanced against the potential impact on the patient experience with these approaches. Future work may focus on the patient experience and satisfaction for each of these care processes.

Unfortunately, these higher costs are not offset by higher reimbursement, as brachytherapy is not included in bundled reimbursement codes for breast IORT. Even though PB-IORT requires significantly more resources when compared to CB-IORT with x-rays or electrons, the bundled reimbursement codes currently only apply to electron beam or the portable x-ray unit that is delivered in a conventional, unshielded operating room when performing CB-IORT. Because PB-IORT utilizes HDR, which consists of gamma rays, clinicians cannot bill for PB-IORT in the same way that they can for CB-IORT. Instead, billing is for a single dose of brachytherapy. For centers considering an integrated brachytherapy suite, it is important to consider the financial impact of moving care to this setting on overall delivery costs. Furthermore, lean management practices may help reduce cost of PB-IORT with either of these delivery approaches (16).

In both settings, the high costs for PB-IORT were associated with physician time and consumable supplies. Anesthesiology costs are significantly higher with an integrated brachytherapy suite, as the anesthesiologist’s time is devoted to covering a single room, rather than multiple as they would in a conventional operating room setting. Therefore, efforts to support the productivity of the other physicians, namely the surgeons and radiation oncologists, during portions of the case where they are not needed are essential to success and financial feasibility. For example, provision of computers for other patient care tasks and access to nearby exam rooms for outpatient care before and after the case reduces the impact of time devoted to PB-IORT. In this manner, for instance, the surgeon has the ability to complete documentation or see clinic patients while not required in the operating room during the delivery of HDR brachytherapy.

Additionally, the brachytherapy applicator that is currently used by both institutions is expensive ($2400) and contributes significantly to the overall cost of the procedure. Similar to our findings, a separate TDABC reported by Schutzer et al. found that the brachytherapy balloon applicator and placement contributed substantially to the delivery cost of accelerated partial breast irradiation (APBI), comprising 49% of the total cost of treatment (17). In the present study, the balloon applicator comprised 60% of the total cost in an integrated facility and 66% of the total cost in a standard, distributed facility. The higher proportion of costs attributable to the balloon applicator in the current study is likely related to smaller overall delivery costs compared to APBI, since only 1 fraction is delivered with IORT. When compared to whole breast irradiation (WBI), Schutzer et al. found APBI to be 30% more expensive (17). By adopting a less expensive brachytherapy applicator, we estimate that we can reduce the cost of consumable supplies by up to 30%.

There are several limitations of the current study. Here, we compare only one site for each method of delivering PB-IORT. Due to differences among institutions in regards to infrastructure, personnel, facilities, and workflow, these results may be specific to the evaluated sites, with limited potential to extrapolate to other centers or make inferences about future centers. This study also does not evaluate the theoretical increase in the effectiveness of PB-IORT when the applicator can be adjusted in real-time with in-room CT imaging at UVA, as this is beyond the scope of the study. Nor does the work evaluate the potential impact of applicator removal and complete would closure by a breast surgeon at UVA, compared to applicator removal through a separate incision by a radiation oncologist at TJU, on cosmetic outcomes and wound healing. The present analysis does not address the cost-effectiveness of PB-IORT, nor does it compare costs associated with this approach to WBI or APBI, which are more common methods of radiation delivery.

Conclusions

In conclusion, the delivery of PB-IORT in an integrated brachytherapy suite is more expensive than performing this procedure with decentralized workflow. Value-based care emphasizes outcomes over cost, and thus further investigation is warranted to weigh the additional cost of PB-IORT in these two settings with patient satisfaction and overall outcomes. TDABC may be utilized by institutions to ensure the delivery of higher value care when integrating new technologies. Although this analysis was limited to breast brachytherapy, these insights may apply to other brachytherapy procedures as well, which may be helpful for centers planning to incorporate an integrated brachytherapy suite.

Supplementary materials


References


