BSc Thesis Industrial Engineering & Management

An economic evaluation of high-dose-rate brachytherapy utilization for prostate cancer in the United States of America

Narcisa Dobre

Supervisors: Xavier Pouwels ,Gréanne Leeftink, Ate Loonstra & Dirk Binnekamp

Department of Industrial Engineering & Management
Faculty of Behavioural, Management and Social sciences

UNIVERSITY OF TWENTE.

An economic evaluation of high-dose-rate brachytherapy utilization for prostate cancer in the United States of America

This report is intended for everyone that is interested in my bachelor's thesis. This thesis will present what I have done for my assignment during module 12 as part of the Industrial Engineering and Management educational program at the University of Twente.

University of Twente, Industrial Engineering and Management
Postbus 217, 7500 AE Enschede
Tel. +31(0)53489911

Maria-Narcisa Dobre, s2453592

First supervisor University: Xavier Pouwels

Second supervisor University: Gréanne Leeftink

Supervisors Company: Ate Loonstra & Dirk Binnekamp

Bachelor thesis: An economic evaluation of high-dose-rate brachytherapy utilization for prostate cancer in the United States of America

Publication date: 7 July 2023

1st Edition

Number of pages: 33

UNIVERSITY OF TWENTE. Elekta

Management summary

This study is conducted at the Elekta facility in Veenendaal. Elekta develops and manufactures radiation therapy solutions, and it is the market leader in brachytherapy solutions. Elekta provides all the radiotherapy equipment (hardware, software, and services) necessary to treat patients diagnosed with cancer in hospitals and clinics worldwide.

Problem description

In the United States, the utilization of brachytherapy treatments for prostate cancer has decreased in favor of alternative radiation therapies such as external beam radiation. This decline is due to a combination of factors, one of which is unfavorable reimbursement for the brachytherapy procedure relative to the time invested by the physicians. Consequently, our research question is:

How can the clinical application of brachytherapy be optimized regarding the current reimbursement policies in the United States?

This thesis aims to investigate the cost-reimbursement difference of brachytherapy clinical applications for prostate cancer in the United States. Our objective is to outline a clinical application that is optimized for reimbursement in the United States without compromising the quality of the treatment, thereby increasing the attractiveness of the economic profile of brachytherapy.

Methods

This study analyzed the most prevalent brachytherapy high-dose-rate (HDR) clinical applications for prostate cancer in the United States of America. We investigated the reimbursement policies, rates, and the clinical application's cost drivers. We designed an optimized clinical application. We calculated the total utilization cost of healthcare delivery for the common clinical application of HDR brachytherapy for prostate cancer in the USA and the optimized clinical application using a time-driven activity-based costing approach. Furthermore, we used the Medicare reimbursement policies and rates for 2023 to calculate the total reimbursement received for each application.

Results

Our study revealed that for the optimized clinical application the total utilization cost decreased by approximately 25%. Medicare reimburses the optimized clinical application with 12% more than the common clinical application. This results in a 26 times higher positive financial result for the optimized clinical application compared to the common clinical application. Moreover, the time of patients under anesthesia in the optimized clinical application has decreased by approximately 32%, which decreases the risk of patients developing adverse events post-treatment (Johnson et al., 2019).

Discussion and conclusion

In this study, we describe an optimized clinical application for HDR brachytherapy for prostate cancer and its most common clinical application, and we conduct an economic analysis of two clinical applications. The cost analysis reveals that the optimized clinical application utilizes fewer resources and is better reimbursed than the common clinical application. In response to these insights, the optimized clinical application can be a potentially attractive choice for healthcare providers once Elekta has also advanced its portfolio in this direction. In addition to financial benefits, the optimized clinical application improves patient safety and treatment precision. Therefore, the optimized clinical application has the potential to improve HDR brachytherapy practice, to the benefit of patients and healthcare providers.

Table of Contents

Glossary

Abbreviation	Definition
ASTRO	American Society for Radiation Oncology
CCR	Capacity Cost Rates
CT	Computed Tomography
EBRT	External Beam Radiotherapy
HDR	High Dose Rate
IMRT	Intensity-Modulated Radiation Therapy
LDR	Low Dose Rate
MPSM	Managerial Problem-Solving Method
MR(I)	Magnetic Resonance (Imaging)
NCCN	National Comprehensive Cancer Network
NCCI	National Correct Coding Initiative
OAR	Organs At Risk
OR	Operating Room
QA	Quality Assurance
SBRT	Stereotactic Body Radiation Therapy
TDABC	Time-Driven Activity Based Costing
TRUS	Trans Rectal Ultrasound
USA	United States of America
UT	University of Twente

1. Introduction

This research aims to investigate the cost-reimbursement difference of high-dose-rate brachytherapy treatments for prostate cancer in the United States of America. We will detail an optimized clinical application for prostate cancer from the reimbursement perspective without compromising the delivered quality quantified via dosimetry of the delivered brachytherapy treatment course. In Section 1.1, we introduce the background of prostate cancer and available therapies, the role of brachytherapy for the treatment of prostate cancer, and the clinical application. We describe the problems associated with brachytherapy treatments in Section 1.2. We will discuss our research questions in Section 1.3.

1.1. Background

Globally, prostate cancer is the second most common form of cancer in men (Cancer Today, n.d.). It is the fourth most common form of cancer, with 1,414,259 new cases expected in 2020, and typically affects middle-aged and elderly men (WCRF International, 2022). Patients with prostate cancer may undergo surgery, active surveillance, external-beam radiotherapy, brachytherapy, cryotherapy, chemotherapy, or a combination of these treatments based on tumor stage, location, patient preference, and health (Eastham et al., 2022).

Brachytherapy is a form of radiation treatment that involves temporarily placing a radioactive source into or close to a lesion to maximize the impact on the tumor and minimize the impact on surrounding healthy tissues (Crook et al., 2020). The American Society for Radiation Oncology (ASTRO) and the National Comprehensive Cancer Network (NCCN) recommend the use of brachytherapy for specific prostate cancer tumor stages and risk categories such as low-risk or favorable intermediate-risk. (Eastham et al., 2022). There are in principle two types of brachytherapy: permanent implants with low dose rate (LDR) radioactive seeds, and temporary implants with a high-dose-rate (HDR) source (*Brachytherapy for Cancer*, 2019). One of the most significant clinical advantages of brachytherapy is the precision of the radiation dose to the tumor, which minimizes damage to the surrounding organs (Crook et al., 2020).

The treatment with brachytherapy differs depending on the stage of the prostate cancer, on the position and the dimension of the tumor within the organ (Jooya et al., 2022). Moreover, the availability of equipment, hospital set-up, and hospital facilities play a role in how clinical applications are performed (Harkenrider et al., 2021). Henry et al. and Crook et al. describe the clinical application of brachytherapy for prostate cancer in the USA (Henry et al, Crook et al 2020). The process can be divided into seven steps (Figure 1).

1) Consultation is the first step in the process, during which the patient is subjected to diagnostic tests including imaging to determine the size, form, and location of the tumor which helps physicians decide on the best method of action.

2) Additional imaging is done. The physicians contour/delineate the tumor and the organs surrounding dimensions and create a pre-application treatment plan. The patient is then prepared by undergoing some local anesthetic.

3) After that, needles are inserted through the perineum into the lesion and fixated. Imaging needs to be performed once more to confirm the position of the needles and enable treatment planning.

4) Needles are reconstructed in the treatment plan and dosimetry is confirmed. Additional needles may be added to improve treatment precision.

5) The treatment plan is evaluated and optimized.

6) The needles are connected to the afterloader which is the unit that contains the radioactive source. After that, the equipment should be evaluated for quality assessment. The actual treatment delivery follows.

7) The removal of the implants and recovery of the patient.

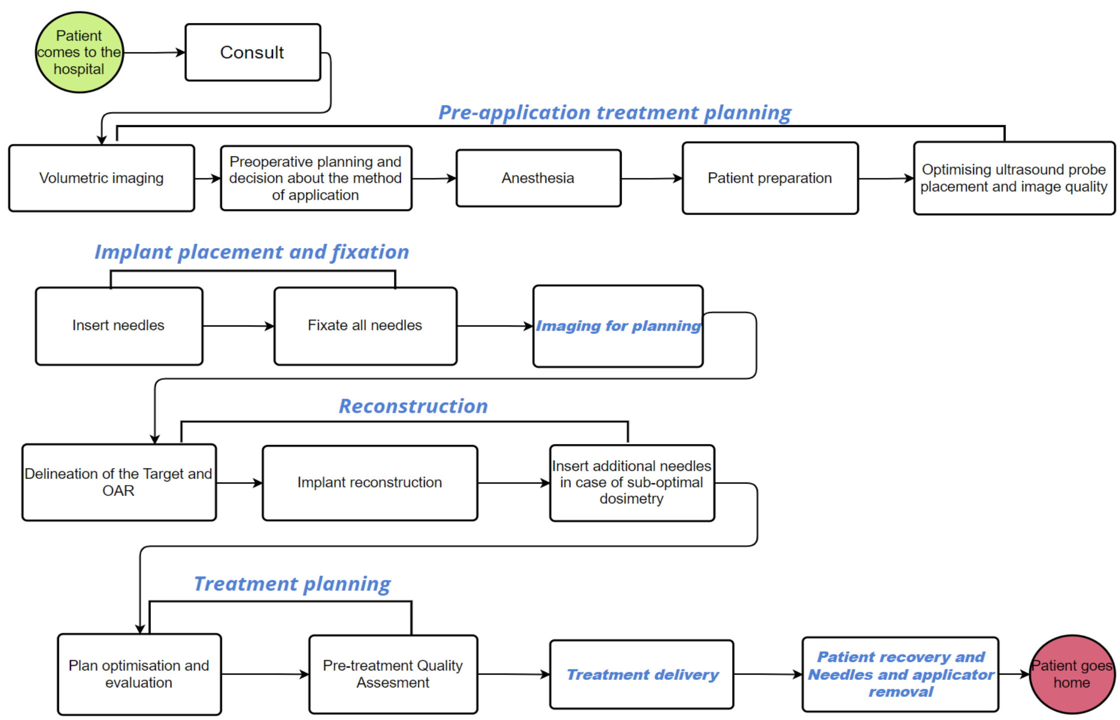


Figure 1 Clinical application of brachytherapy for prostate cancer

1.2. Problem description

The American Society for Radiation Oncology (ASTRO) and the National Comprehensive Cancer Network (NCCN) recommend the use of brachytherapy for specific tumor stages and risk categories (Eastham et al., 2022). However, there is a declining utilization of this treatment compared to alternative radiation therapies such as external beam radiation (Andring et al., 2021). The cause of this decline is probably multifactorial, one of them being unfavorable reimbursement for the HDR brachytherapy (Andring et al., 2021). In the USA, the reimbursement for radiation therapies is based on a 'fee for service' payment (Rice et al., 2021). Because of the long duration of a clinical application, the number of brachytherapy fractions that can be delivered per day is low (Vu et al., 2020). The personnel time, the number of fractions delivered, the equipment investment, and the duration of the procedure affect the ratio of total costs and reimbursement which impacts the economic profile of HDR brachytherapy (Mulherkar et al., 2021). The action problem of our research is:

The economic profile of HDR brachytherapy may not be attractive to healthcare providers in the USA.

Therefore, this thesis aims *to* conduct an economic evaluation of HDR brachytherapy utilization for prostate cancer in the USA. We aim to propose an alternative for today's average clinical applications to become more reimbursement optimized in the US without compromising the quality of the treatment. We expect that the implementation in clinical practice will positively impact the utilization of HDR brachytherapy treatments for prostate cancer in the USA such that more patients could benefit from its clinical advantages.

1.3. Research (sub) question

Radiation alternatives such as intensity-modulated radiation therapy (IMRT) and stereotactic body radiation therapy (SBRT) are replacing brachytherapy in the United States (Vu et al., 2020). Elekta is interested in increasing brachytherapy utilization in the United States by developing future technology that makes the treatment more appealing to healthcare providers. Based on the action problem from Section 1.2, "the economic profile of brachytherapy may not be attractive to healthcare providers," we formulate the following research question:

How can the clinical application be optimized regarding the current reimbursement policies in the United States?

1.3.1. Sub questions

To assist in addressing the research topic, we have identified the following sub-questions:

1. How can the clinical application be **optimized considering the currently available reimbursement policies** in the USA?
    a. How does **today's average clinical application HDR Brachytherapy prostate** look like in the USA?
    b. What are the **reimbursement policies and payment structures** in USA public and private reimbursement settings?
2. What is the estimated **total utilization cost per patient** for the HDR clinical application in the USA?
3. How do the changes in performing the clinical applications of brachytherapy radiation treatments for prostate cancer affect the **cost-reimbursement difference** of the treatment in the USA?

1.3.2. Research design

We use the Managerial Problem-Solving Management (MPSM) approach to conduct this research. Cooper and Schindler (2013) outline the seven phases of this methodology. The first, "problem identification," was illustrated in Section 1.2. of this thesis. "Solution planning," is covered by providing an overview of the research questions we must answer. We cover the third phase 'problem analysis' by answering the first sub-question to define an optimized clinical application and assess its viability by consulting with medical experts. We cover the 'solution generation' and 'solution selection' phases by responding to the second sub-question, as a result of utilizing the cost analysis method to calculate the total utilization cost. The 'solution implementation' and 'solution evaluation' phases relate to the third sub-question that compares the two cost-reimbursement differences for the optimized clinical application and the common clinical application in the USA.

2. Methodology

In this section, we will discuss the data collection and analysis methodologies. In Section 2.1, we describe the common and optimized clinical applications. Then, in Section 2.2, we will define reimbursement policies and rates. Furthermore, we describe the time-driven activity-based costing method in Section 2.3 and we discuss the methods to calculate the cost-reimbursement differences for the clinical applications in Section 2.4. Finally, we discuss the sensitivity analysis in section 2.5.

2.1. The most common clinical application and the optimized clinical application

To develop a clinical application alternative that is optimized for reimbursement, we analyzed how the treatments are currently delivered in the USA. Elekta sent a survey to brachytherapy customers in the United States. In the survey, respondents were asked which HDR clinical application they perform for prostate cancer and how it is executed, as well as the average amount of time required to complete each stage and who is the main performer. More about the survey can be found in *Analysing Workflows of High Dose Rate Brachytherapy Treatments for Prostate Cancer in the USA - University of Twente Student Theses*. The results of the survey determined the most common clinical application performed. The survey results revealed that nine out of nineteen respondents conduct real-time treatment planning which means that they verify the dosimetric effect of the implant during the insertion of the implant.

To optimize the clinical application, we looked at the reimbursement regulations, cost drivers, and the activities that consume the most time in the most common clinical application. We conducted a systematic review of the literature to identify the reimbursement policies in the USA, and potential time and money-saving solutions. Conversely, we confirmed that the clinical application's actions satisfied the eligibility requirements for reimbursement by consulting with reimbursement policy experts.

2.2. Reimbursement estimates for the clinical applications

The reimbursement system in the USA for HDR brachytherapy involves a combination of technical and professional fees, which are billed through the Current Procedural Terminology (CPT) codes to insurance companies or Medicare for reimbursement. Table 1 shows the equivalent reimbursement terms and CPTs used for the sub-activities in the common clinical application, as well as their rates according to the Medicare National Correct Coding Initiative (NCCI) Policy Manual (Medicare NCCI Policy Manual | CMS, n.d.).

Table 1 Reimbursement codes for the Common clinical application

Main activity	Sub activity	Descriptor using NCCI	CPT Code	Profesional component rate	Technical component rate	Total
Consult	New Patient Consultation	New patient visit	**99204**	$133.52	$0.00	$133.52
	Physician clinical treatment solution	Physician clinical treatment planning	**77263**	$170.11	$0.00	$170.11
Pre-application treatment planning	Anesthesia	Moderate sedation	**99156**	$75.91	$0.00	$75.91
	Patient preparation	Included in the bundle for Implant placement		$0.00	$0.00	$0.00
	Acquire Ultrasound Image	Simulation (Set radiation therapy field)	**77290**	$83.02	$358.72	$441.74
	Delineation: target and OARs Acceptance fused volume Adjust treatment plan Acceptance treatment plan	3D Radiotherapy	**77295**	$248.05	$1,340.67	$1,588.72
Implant placement	Insert the needles & Fixate needles	Transperi needle placement prostate & Echo Guidance Radiotherapy	**55875** **76965**	$780.08 $67.10	$4,702.18 $0.00	$5,482.26 $67.10
Imaging for planning	Acquire Ultrasound Image	Simulation (Set radiation therapy field)	**77290**	$83.02	$0.00	$83.02
	Adjust delineation and treatment plan	3D Radiotherapy	**77295**	$248.05	$1,340.67	$1,588.72
Implant reconstruction	Implant reconstruction	Transperi needle placement prostate & Echo Guidance Radiotherapy	**55875** **76965**	$780.08 $67.10	$4,702.18 $0.00	$5,482.26 $67.10
Treatment planning	Final treatment delivery plan	3D Radiotherapy	**77295**	$248.05	$1,340.67	$1,588.72
		Special medical radiation physicist	**77470**	$0.00	$133.38	$133.38
Treatment delivery	Connect afterloader	Radiation treatment aid(s)	**77323**	$24.06	$133.38	$157.44
	Quality assesment	HDR Iridium Source	**C1717**	$0.00	$335.71	$335.71
	Dose delivery	HDR Brachytherapy Treatment delivery	**77772**	$283.64	$721.72	$1,005.36
Patient recovery and needles removal	Implant removal	Included in the bundle for Implant placement		$0.00	$0.00	$0.00

2.3. Time-Driven Activity-Based Costing (TDABC) method

To find the most suitable approach for the cost analysis, we conducted a systematic literature review. We decided to use the time-driven activity-based costing (TDABC) method. The TDABC method is a costing method used in management accounting to determine the cost of products, services, or activities based on the time required to perform them (Mulherkar et al., 2021). Costs are assigned to products and services according to the quantity of time spent on each activity involved in their delivery. According to Mulherkar et al. (2021), the TDABC methodology is a strategy that consists of seven steps:

1. Select the treatment
2. Identify the care delivery chain by documenting the activities that needs to be delivered
3. Process map that includes all the activities in the clinical application and the needed resources with respect to the personnel, facility, equipment and disposable supplies.
4. Estimate the time that is needed for each activity
5. Approximate the costs of delivering each activity
6. Estimate the costs for each cost driver based on the time that they are used
7. Calculate the total cost.

The first step of the TDABC method is to select the treatment. In our case, we will analyze the HDR brachytherapy treatments for prostate cancer in the USA. The second step which is the delivery path of this clinical application includes the following procedures: diagnosis and treatment planning; pre-implantation preparation; placement of the implant in the prostate; imaging and final treatment planning; delivery of high-dose radiation using a remote-afterloading machine through the implant and removal of needles.

Cost drivers are the factors that substantially impact expenditures on medical treatments. We identify four cost drivers for HDR brachytherapy treatments: personnel, equipment, infrastructure costs, and consumable supplies. The personnel expenses include healthcare professionals ’salaries. The equipment costs include the initial purchase cost, annual maintenance costs, and annual contractual fees (Li et al., 2023). Infrastructure costs refer to as operating room (OR) costs. For HDR brachytherapy for prostate cancer, the list of equipment includes the Flexitron, which is the machine that delivers the therapeutic dose to the tumor using a radioactive source, the Prostate Template that facilitates insertion of the needles, and the Oncentra Prostate Software and Hardware that ease treatment planning. The consumable supplies include a list of all medications and tests utilized during the intervention, which includes transrectal ultrasound imaging, MRI, CT scan, and anesthesia.

Based on the findings of the survey, and publications by Crook et al. (2020) and Dutta et al. (2018) regarding the brachytherapy intervention and dose delivery, an overview was created that outlines the cost drivers and their respective factors for each activity (Table 2).

Table 2 Cost drivers and cost factors (Crook et al., 2020, Dutta et al., 2018)

Main Activity	*Cost driver*	*Cost Factors*
Preparation of a new patient	Physician consultation fees, facility fees, and administrative costs.	Duration and complexity of the consultation, the expertise of the physician, geographical location.
Treatment planning	Personnel fees, imaging costs (e.g., MRI, US), and delineation software.	The complexity of the treatment plan, number and type of imaging studies required, use of advanced treatment planning techniques, and personnel expertise.
Implant Placement and Fixation	Personnel fees, equipment in the operating room and treatment planning software and supplies (number of needles inserted).	Surgical complexity
Update treatment plan in case of significantly changed anatomical structure	Personnel fees, Imaging modality costs (US image set costs), and treatment planning software.	Type and number of imaging studies performed, need for additional imaging techniques (e.g., fusion imaging), imaging facility fees
Implant reconstruction	Personnel fees, equipment in the operating room and treatment planning software and supplies (number of needles inserted).	Surgical complexity
Final treatment delivery plan	Personnel fees, treatment planning software, and computing resources.	The complexity of the treatment plan, use of advanced planning algorithms, personnel expertise, software fees
Treatment delivery and implant removal	Personnel fees, equipment usage costs, consumables (e.g., applicators, gels), and facility fees.	Treatment duration, number of treatment fractions, the complexity of treatment delivery, equipment depreciation and maintenance costs, consumable quantities
Patient Recovery and Needle Removal	Nursing staff fees, recovery room costs, disposables (e.g., dressings, bandages).	Duration of recovery, nursing care requirements, use of specialized wound care products.

2.3.1. Process map with time estimates for the common clinical application

The third and fourth steps of the TDABC methodology are to identify the performer and the quantity of time required for each activity. We take the performer who has appeared the most frequently in answers for each activity from the results of the survey. For the time, we used the mean value for each sub-activity from the results of the survey. Therefore, Figure 2 displays the process plan using the values from the survey.

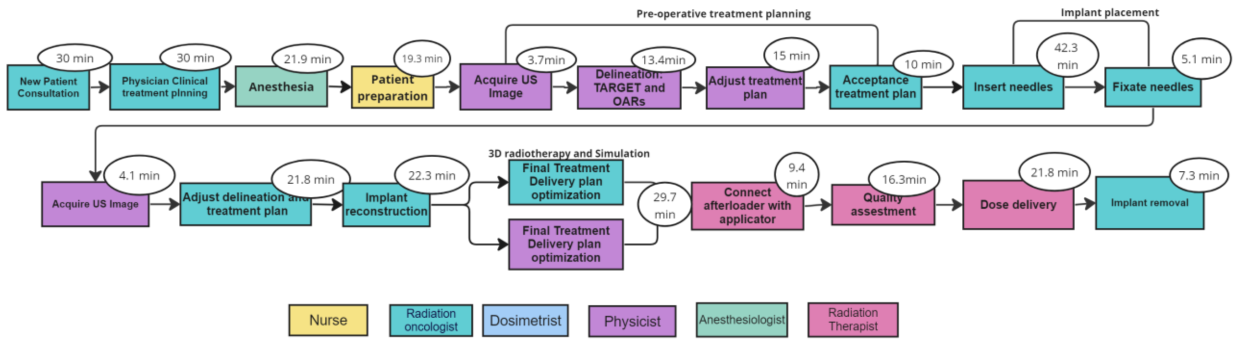


Figure 2 Process map of the most common clinical application

2.3.2. Process map with time estimates for the optimized clinical application

The optimized clinical application has not been performed yet. We make assumptions to estimate the time required for each individual activity based on its similarity with the results of the survey regarding the clinical application that uses real-time planning and MRI registration. Since our objective is to maximize reimbursement, we predicted who will perform the activities based on the reimbursement policies and survey results regarding the most frequent performer in the clinical application that uses real-time planning and MRI registration.

2.3.3. Input values

The next step of the TDABC methodology is to estimate the cost of delivering each activity using the cost drivers. The following tables provide information regarding personnel salaries, the cost of equipment and its maintenance, the cost per minute of the operating room, an estimate of the annual number of patients, and the cost of intraoperative consumables. Literature offers parameter input values and material quantities. The hourly wages found in literature are shown in Table 3 (Parikh et al., 2020, Physician Assistants, 2023). Table 4 displays the list of intraoperative costs suggested by Dutta et al. (2018) and

Alyamani et al. (2021). Based on Solodkiy et al. (2022), we estimated the average number of patients per year to be 32. Product Management at Elekta provided information on the equipment costs.

Table 3 Personnel wages

Personnel	***Wage/hour***	**Cost per minute**	***Reference***
Radiation Oncologist	$309.60	$5.16	(Parikh et al., 2020) and (Physician Assistants, 2023)
Dosimetrist	$136.20	$2.27	
Nurse	$145.20	$2.42	
Physicist	$153.60	$2.56	
Urologist	$196.00	$3.27	
Physician assistant	$75.75	$1.26	
Radiation Therapist	$126.60	$2.11	
Office Assistant	$58.20	$0.97	
Anestheologist	$145.66	$2.43	
Other	$0.00	$0.00	

Table 4 Consumable supplies

Consumable supplies	**Cost**	**Quantity**	**Reference**
Needles	$32.29	17	(Dutta et al., 2018)
Imaging(MRI)	$1,325.00	1	(Enhance Health, 2023)
Sequential Compression Device Set	$78.77	1	(Dutta et al., 2018)
Sterile surgical gowns	$3.44	6	
Sterile surgical gloves	$1.87	6	
Surgical masks	$0.83	6	
9 inch foam donut	$13.60	1	
Eggcrate foam pad	$1.72	2	
Bair hugger	$9.72	1	
Stirrup strap with slip ring	$4.73	2	
Iothalamate Meg 60/50 mL vial	$12.61	1	
Check-Flo Adapter 9F	$11.73	1	
22-French Foley Catheter	$9.61	1	
18-French Council Tip Foley Catheter	$15.43	1	
Urine drainage bag 2000 mL	$4.32	1	
Ultrasound probe drape	$8.62	1	
Exam room supplies	$0.18	1	(Alyamani et al., 2021)
Imobilization devices(multiuse)	$0.52	1	
Office supllies	$2.41	1	
Patient supplies	$1.57	1	
Radioactive source	$156.52	1	
Cleaning, Disinfectants agents and Disposal Supplies	Included in the overhead cost		(Alyamani et al., 2021)

2.3.4. Calculate the capacity cost rates and total cost

The capacity cost rates (CCR) are the estimators of the costs for each cost driver based on the amount of time that they are used. We will use this measurement to determine the cost per minute of using the personnel and equipment. For consumable supplies, we assign the material cost to the activities need the materials from the list of materials. In our case, we distinguish the following formulas for CCRs:

- ***Personnel CCR per minute***: $CCR_{Personnel}$ = (Hour Wage of personnel) / 60 minutes
  - The CCR needs to be calculated for each personnel (Radiation Oncologist, Anesthesiologist, Nurse, Physicist, Radiation Therapist, Dosimetrist)
- ***Equipment CCR per minute***: $CCR_{Equipment}$ = ((Initial Purchase/ Expected lifespan + Annual Maintenance Cost) *1.2) /(The number of treatments per year * The number of minutes in usage per treatment)
  - Since the literature regarding the total usage time per year of the equipment is limited, we assume that the cost of treatment is the same for all patients that receive the treatment. Therefore, to determine the CCR per minute, we divide the cost of equipment for a single treatment by the total time the equipment was utilized during that brachytherapy intervention.
  - According to Alyamani et al. (2021), by multiplying the cost by a factor 1.2, we cover the indirect cost incurred for activities such as cleaning and energy supply.

The final step is to calculate the total utilization cost, which is obtained by multiplying the CCR with the process time and summing to calculate the total cost (Mulherkar et al., 2021).

- **TotalCost** $_{personnel}$ = $\sum\sum CCR_{personnel} * \text{Sub-ActivityTime}_{Personnel}$, where we sum the personnel costs for each personnel for each activity that he/she performs
- **TotalCost** $_{Equipment}$ = $\sum CCR_{Equipment} * \text{Sub-ActivityTime}_{Equipment}$, where we sum the costs of all the sub-activities that require the use of equipment: all activities included in the treatment preparation, acquiring ultrasound image set, delineation target and OARs, creation and acceptance treatment plan and all activities included in implant insertion, imaging for planning, implant reconstruction, final treatment planning and treatment delivery
- **TotalCost** $_{OR}$ = $\sum \text{Cost\_minute\_OR} * \text{Sub-ActivityTime}_{OR}$, where we sum the OR cost of all the sub-activities that use OR
- **TotalCost** $_{Consumable}$ is the sum of all the materials that are needed during the intervention

Total Cost = **TotalCost** $_{personnel}$ **+ TotalCost** $_{Equipment}$ **+ TotalCost** $_{OR}$ **+ TotalCost** $_{Consumable}$

2.4. Method to determine the cost-reimbursement difference

To estimate the total utilization cost of HDR brachytherapy treatments for prostate cancer in the United States and the potential payment using the Medicare reimbursement rates, we used a spreadsheet simulation. Firstly, it contains all the cost components that allow for the calculation of the total utilization cost of the intervention and offer insight into the resource allocation for each activity in the clinical application. Secondly, it includes the Medicare reimbursement rates to estimate the payment. In order to facilitate deducting the cost-reimbursement difference for each activity, we made the following assumptions:

- The OR cost per minute is $46.04 (Smith et al., 2022). However, the cost of the OR is reimbursable only in the bundle payment for the implant insertion. We want to compare the cost and the reimbursement for each service. Therefore, we used an **Adjusted** $\mathbf{\_CCR_{OR}}$ which is the adjusted cost per minute for the OR time and covers total OR time assigned to the activities that get reimbursed for it, such as insertion of the needle, fixation of the needles, and implant reconstruction. The value for $\mathbf{TotalCost_{OR}}$ will not be changed due to the **Adjusted** $\mathbf{\_CCR_{OR}}$.
    - **Adjusted** $\mathbf{\_CCR_{OR}}$ = ($46.04 * Total time in OR)/(time for insertion of the needles + time for fixation of the needles + time for implant reconstruction)
    - $\mathbf{TotalCost_{OR}} = \sum \text{Adjusted } \_CCR_{OR} * \text{Sub-ActivityTime}$, where we sum the OR cost of all the sub-activity that receive reimbursement for OR cost: insertion of the needles, fixation of the needles and implant reconstruction
- It is essential that the spreadsheet simulation is flexible in order to account for the almost yearly changing prices and reimbursement rates. Because of this, all input values can be changed, and the user can adjust the duration of each activity as well as the person responsible for carrying it out by simply modifying the relevant input values on the user form.

The spreadsheet simulation provides a dashboard for the communication and reporting of the main findings, including the costs and reimbursement for each activity and the total time and patient time under anesthesia.

2.5. Sensitivity analysis

In our analysis, we select one performer per sub-activity of the clinical applications. In practice, there may be more personnel involved in each step, which can cause an underestimation of personnel fees. For each sub-activity of treatment planning, implant insertion, and treatment delivery, we added one more physician and we simulated with these input variables in the spreadsheet simulation. Figure 3 shows the process map with the added performers for the mentioned activities for the common clinical application.

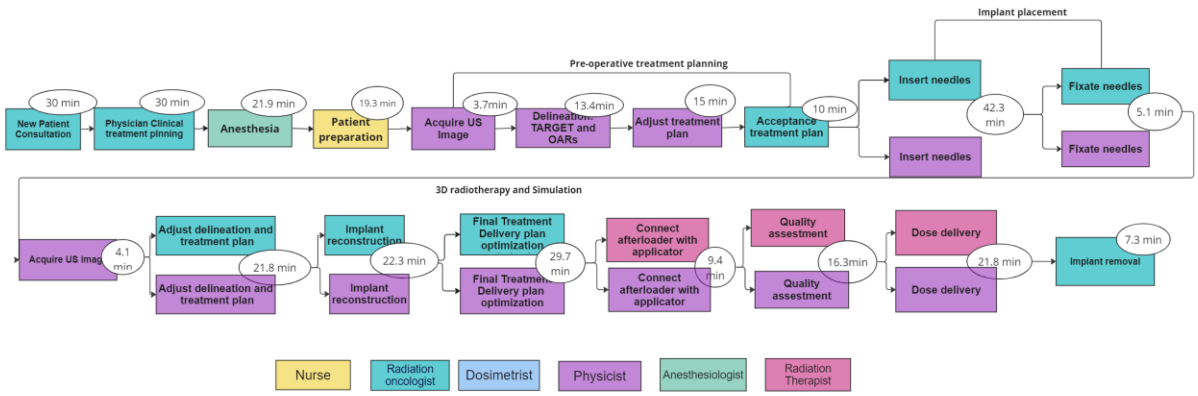


Figure 3 Process map of the sensitivity analysis of the common clinical application

According to Solodkiy et al. (2022), we estimated the number of patients per year to be 32. We carried out a sensitivity analysis to determine how increasing the number of patients affects the equipment cost per patients and its impact on the total utilization cost. Moreover, literature is used to derive the value of indirect costs. However, hospitals may account for indirect costs differently. Therefore, we investigated it in a sensitivity analysis.

3. Results

In this section, we discuss the results. Firstly, we calculated the cost-reimbursement difference for the common clinical application in Section 3.1. After that, we calculated the cost-reimbursement difference for the optimized clinical application in Section 3.2. Subsequently, we compared the two clinical applications in Section 3.3 and determined the main differences in clinical applications' time, costs and reimbursement.

3.1. Cost-reimbursement difference for the common clinical application

The total costs and reimbursement for the common clinical application were calculated using the spreadsheet simulation (Figure 4). The total cost is $16,890.06 and the total reimbursement is $17,133,86 which leads to a $243.80 profit per patient. A detailed overview of costs and reimbursement of each activity can be found in Table 5.

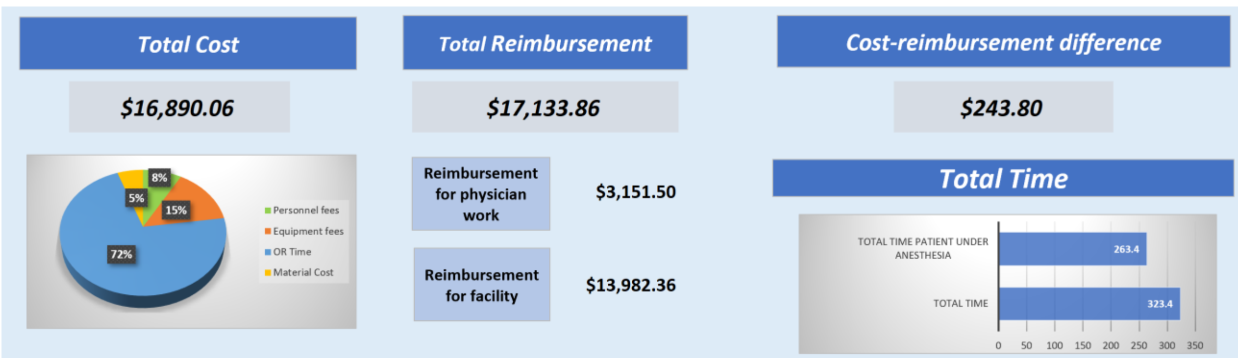


Figure 4 Spreadsheet simulation results for the common clinical application

Table 5 Cost-reimbursement difference for the common clinical application

Main activity	Sub activity	Cost	Reimbursement	Profit/Loss
Consult	New Patient Consultation	$154.80	$133.52	-$21.28
	Physician clinical treatment solution	$154.80	$170.11	$15.31
Treatment preparation	MR Imaging for volume delineation	$0.00	$0.00	$0.00
	Data selection and import			$0.00
	Delineation: target and OARs	$0.00	$0.00	$0.00
	Acceptance treatment plan			$0.00
Pre-application treatment planning	Anesthesia	$53.17	$75.91	$22.74
	Patient preparation	$248.40	$0.00	$0.00
	Acquire Ultrasound Image	$48.14	$150.12	$101.98
	Delineation: target and OARs	$174.34	$1,588.72	$1,063.12
	Acceptance fused volume	$0.00		
	Adjust treatment plan	$195.16		
	Acceptance treatment plan	$156.10		
Implant placement	Insert the needles	$8,403.02	$5,482.26	-$4,173.78
	Fixate needles	$966.95		
Imaging for planning	Acquire Ultrasound Image	$53.34	$150.12	$96.78
	Adjust delineation and treatment plan	$340.31	$1,588.72	$708.75
Implant reconstruction	Implant reconstruction	$4,611.06	$5,482.26	$871.20
Treatment planning	Final treatment delivery plan	$539.66	$0.00	$0.00
Treatment delivery	Connect afterloader	$118.07	$2,312.12	$1,558.98
	Quality assesment	$204.74		
	Dose delivery	$430.34		
Patient recovery and needles removal	Implant removal	$37.67	$0.00	$0.00
Total		**$16,890.06**	**$17,133.86**	**$243.80**

As Table 5 shows, there is a 1.44% profit when subtracting total utilization cost from Medicare reimbursement per patient. The activity that is causing the highest loss is the implant placement. According to the Medicare NCCI Policy Manual, the insertion of implant and treatment planning activities are bundled payments. For example, the insertion of implant includes all costs, such as OR time, equipment, and personnel. However, the amount of time spent on this activity has no bearing on the reimbursement. The cost exceeds the reimbursement due to the extensive amount of time spent conducting the activity, which utilizes costly resources such as the operating room (OR).

3.2. Cost-reimbursement difference for the optimized clinical application

We calculated the total cost and reimbursement using the simulation spreadsheet using the input values for the optimized clinical application (Figure 5). The total cost for the optimized clinical application is $12,634 and the total reimbursement is $19,164 which leads to a $6,530 surplus.

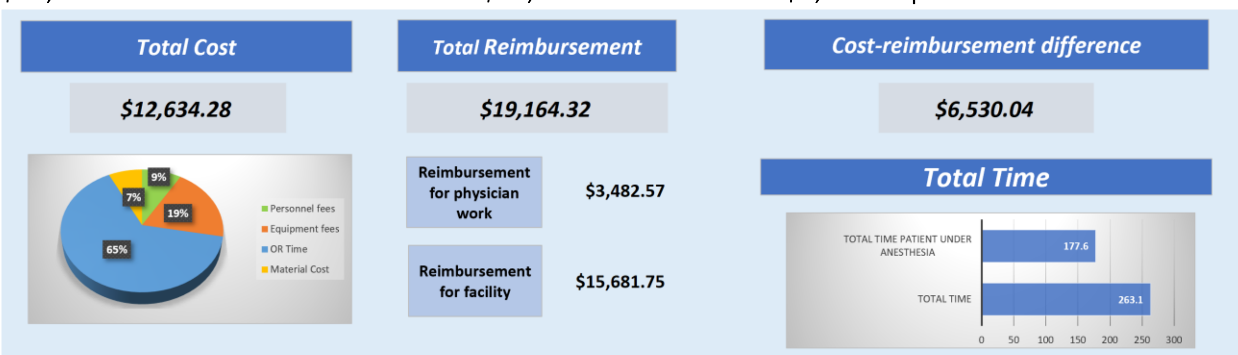


Figure 5 Spreadsheet simulation results for the optimized clinical application

The primary observation is that there is no discrepancy between costs of activities and Medicare reimbursement for all brachytherapy-related activities. The only service that is not fully reimbursable is the clinical consultation with a new patient. On the other side, the treatment preparation has the highest cost-reimbursement difference. Similarly, the cost-reimbursement differences for treatment optimization services such as pre-application treatment planning, imaging for planning, and implant placement are favorable.

3.3. Comparative analysis

To determine the differences between the two clinical applications, we evaluate them based on various criteria. The comparison of the total duration of brachytherapy intervention and the total time of the patient under anesthesia is performed in section 3.3.1, while the total cost of utilization is analyzed in section 3.3.2. Furthermore, the total reimbursement is investigated in section 3.3.3, and the cost-reimbursement difference is examined in section 3.3.4.

3.3.1. Comparison between the duration of the two clinical applications

Table 7 presents the differences in time between the common and the optimized clinical application. As can be seen, there is an estimated reduction of 60.3 minutes (-18.6%) in the total time needed for the optimized clinical application compared to the common clinical application. As a result, the total patient time under anesthesia decreased by 85,8 minutes (approximately 32%) (Figure 7). However, it needs to be considered that the time for the optimized clinical application is based on our assumptions mentioned in Section 2.3.2.

Table 7 Difference in time in minutes between the two clinical applications

	Activity	Time for the common clinical application	Time for the optimized clinical application	Diiference in time in minutes
Consult	Clinical vist	30	30	0
	Physician clinical treatment planning	30	30	0
Treatment preparation	MR Image	0	6.5	6.5
	Data selection and import	0	5	5
	Delineation: target and OARs	0	4	4
	Create treatment plan	0	10	10
Pre-application treatment planning	Anesthesia	21.9	17.5	-4.4
	Patient preparation	19.3	12.5	-6.8
	Acquire Ultrasound Image	3.7	3.7	0
	Delineation: target and OARs	13.4	4	-9.4
	Acceptance fused volume	0	3	3
	Adjust virtual plan	15	15	0
	Acceptance virtual plan	10	7.5	-2.5
Implant placement and fixation	Insert needles	42.3	16	-26.3
	Fixate needles	5.1	1	-4.1
Imaging for planning	Acquire Ultrasound Image	4.1	4.1	0
	Adjust delineation:target and OARs	21.8	5	-16.8
Implant reconstruction	Implant reconstruction	22.3	20	-2.3
Treatment planning	Treatment optimization	29.7	13.5	-16.2
Treatment delivery	Connect afterloader	9.4	9.4	0
	Quality assesment	16.3	16.3	0
	Dose delivery	21.8	21.8	0
Patient recovery and needles removal	Implant removal	7.3	7.3	0
Total		**323.4**	**263.1**	**-60.3**

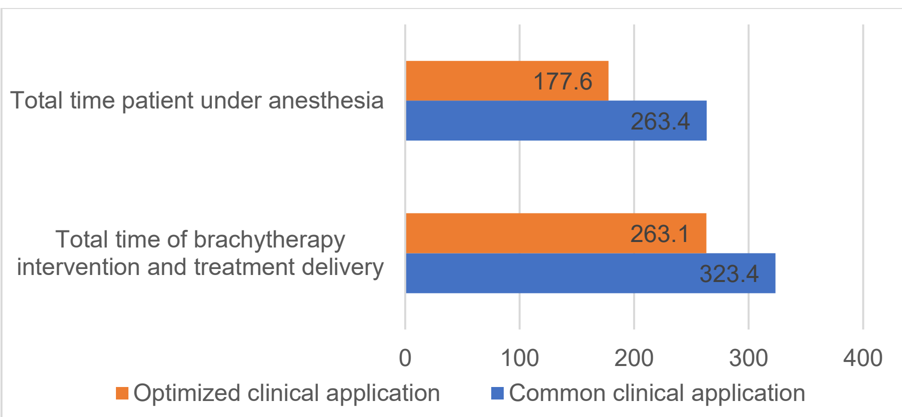
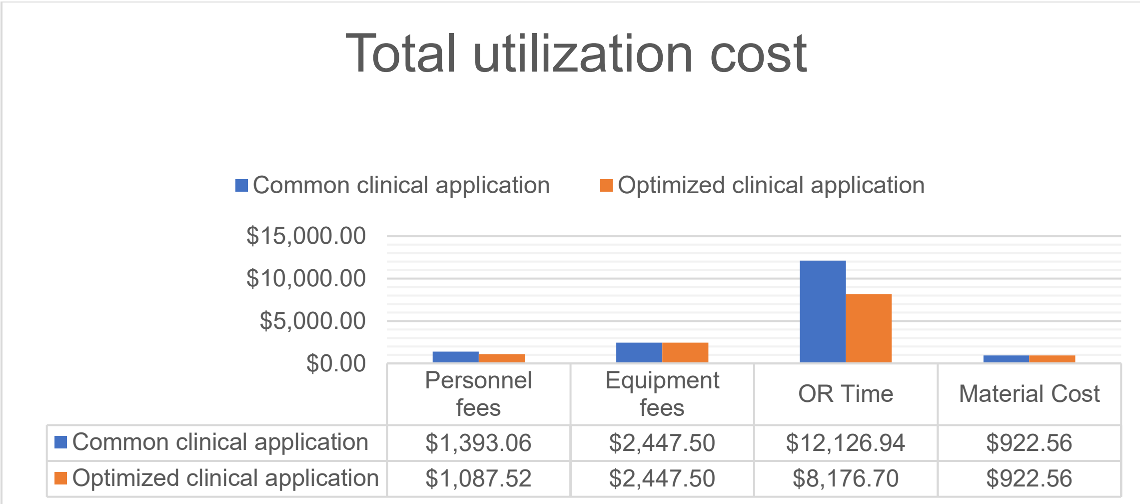


Figure 7 Difference in time in minutes under anesthesia

3.3.2. Comparison between the total utilization costs

Figure 8 shows that the biggest difference in total utilization costs comes from the difference in OR costs between the two clinical applications. The main cause is the duration of brachytherapy intervention. The common clinical application costs $12,126.94 for OR time, while the optimized clinical application cost $8,176.70. Therefore, the decrease of $4,275.09 for the optimized clinical application is due to the lower time spend in the OR.

Figure 8 Total utilization cost for the two clinical applications



Radiation oncologists, medical physicists, radiation therapists, dosimetrists, and nursing staff are the personnel involved in these HDR brachytherapy procedures. For the common clinical application, the cost for personnel is $1,393,06 and for the optimized clinical application it is $1,087,52. Therefore, we observe that the optimized clinical application decreases the personnel cost by almost $306 per patient compared to the common clinical application. The assignment of tasks, such as delineation of tumor and organs at risk to dosimetrists, who are relatively less expensive, may be a factor contributing to the decreased total cost of personnel in optimized clinical application.

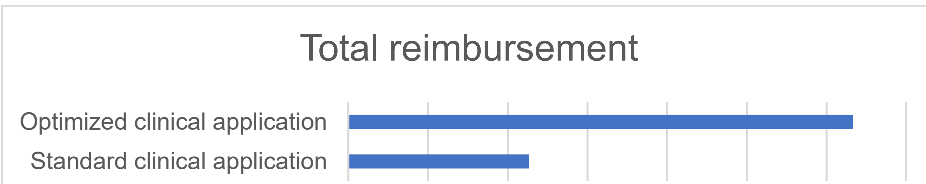
Table 8 Comparison between the total cost

Main activity	Sub activity	Cost standard	Cost optimized	Difference
Consult	New Patient Consultation	$154.80	$154.80	$0.00
	Physician clinical treatment solution	$154.80	$154.80	$0.00
Treatment preparation	MRI for volume delineation registration	$0.00	$105.86	$105.86
	Data selection			$359.60
	Delineation: target and OARs	$0.00	$359.60	$0.00
	Create treatment plan			$0.00
Pre-application treatment planning	Anesthesia	$53.17	$42.48	-$10.68
	Patient preparation	$248.40	$201.84	-$46.56
	Acquire Ultrasound Image	$48.14	$58.60	$10.46
	Delineation: target and OARs	$174.34	$63.99	-$110.35
	Acceptance fused volume	$0.00	$56.66	$56.66
	Adjust treatment plan	$195.16	$244.30	$49.15
	Acceptance treatment plan	$156.10	$141.65	-$14.45
Implant placement	Insert the needles	$8,403.02	$4,221.08	-$4,181.94
	Fixate needles	$966.95	$239.88	-$727.07
Imaging for planning	Acquire Ultrasound Image	$53.34	$64.93	$11.59
	Adjust delineation and treatment plan	$340.31	$107.23	-$233.07
Implant reconstruction	Implant reconstruction	$4,611.06	$5,180.60	$569.54
Treatment planning	Final treatment delivery plan	$539.66	$289.53	-$250.13
Treatment delivery	Connect afterloader	$118.07	$148.87	$30.80
	Quality assesment	$204.74	$258.14	$53.41
	Dose delivery	$430.34	$501.76	$71.43
Patient recovery and needles removal	Implant removal	$37.67	$37.67	$0.00
Total		**$16,890.06**	**$12,634.28**	**-$4,255.78**

Based on Table 8 that presents the cost for each activity, we distinguish the following major decreases in cost for the optimized clinical applications: insertion of the needles, fixation of the needles, the final treatment delivery plan, and the adjustment of the treatment plan. We notice that the implant insertion cost incurred by performing the common clinical application is almost double compared to the optimized clinical application.

The optimized clinical application costs $4,255.79 (-25%) less than the common clinical application. However, some activities in the optimized clinical application cost more compared to the most common clinical application. For instance, the implant reconstruction for the optimized clinical application costs $569.54 more compared to the common clinical application. This is primarily due to the value for the Adjusted $\_CCR_{OR}$ which calculates the cost of OR only for the insertion of the implant and reconstruction of the implant services because these are the services where the OR time is reimbursed. For example, the Adjusted $\_CCR_{OR}$ is $172.98 per minute for the common clinical application and $220.992 per minute for the optimized clinical application.

3.3.3. Comparison of the reimbursement



	Standard clinical application	Optimized clinical application
Total reimbursement	$17,133.86	$19,164.32

Figure 9 Comparison of the reimbursement

Comparing the two clinical applications for HDR brachytherapy based on reimbursement rates (Figure 9), we observe that the reimbursement for the optimized clinical application increases by $2,030.46 (+12%) compared to the reimbursement for the common clinical application.

3.3.4. Comparison of the cost-reimbursement difference

Table 9 Cost-reimbursement differences between the two clinical applications

Main activity	Sub activity	Profit/Loss		Differences
		Standard procedure	Optimized pocedure	
Consult	New Patient Consultation	-$21.28	-$21.28	$0.00
	Physician clinical treatment selection	$15.31	$15.31	$0.00
MR Pre-plan	MR Imaging for volume delineation	$0.00	$335.88	$335.88
	Data selection and import	$0.00		
	Delineation: target and OARs	$0.00	$1,229.12	$1,229.12
	Create treatment plan	$0.00		
Pre-application treatment planning	Anesthesia	$22.74	$33.43	$10.68
	Patient preparation	$0.00	$0.00	$0.00
	Acquire Ultrasound Image	$101.98	$91.52	-$10.46
	Delineation: target and OARs	$1,063.12	$1,082.12	$19.00
	Acceptance fused volume			$0.00
	Adjust treatment plan			$0.00
	Acceptance treatment plan			$0.00
Implant placement	Insert the needles	-$4,173.78	$781.80	$4,955.57
	Fixate needles			
Imaging for planning	Acquire Ultrasound Image	$96.78	$85.19	-$11.59
	Adjust delineation and treatment plan	$708.75	$1,191.95	$483.20
Implant reconstruction	Implant reconstruction	$871.20	$301.66	-$569.54
Treatment planning	Final treatment delivery plan	$0.00	$0.00	$0.00
Treatment delivery	Connect afterloader	$1,558.98	$1,403.35	-$155.63
	Quality assesment			$0.00
	Dose delivery			$0.00
Patient recovery and needles removal	Implant removal	$0.00	$0.00	$0.00
Total		$243.80	$6,530.04	$6,286.24

The cost-reimbursement difference for the optimized clinical application increased by $6,286.24 compared to the common clinical application (Table 9). The higher cost-reimbursement difference associated with optimized clinical application can be explained by factors such as the treatment planning, which reduces brachytherapy intervention time, and better reimbursement.

When comparing the cost-reimbursement difference between the common clinical application and the optimized clinical application, the activities in treatment preparation, the implant insertion, and adjustment of the treatment plan are the ones with the biggest difference. The reimbursements for these activities are bundle payments that cover other activities as well. For instance, the implant insertion payment bundle includes the total cost of OR time, patient preparation, needle insertion, needle fixation, and implant removal. While the cost-reimbursement difference for the insertion of needles is negative for the common clinical application, with a loss of $4,173.78, the optimized clinical application earns $781.80. Hence, this discrepancy between the cost-reimbursement difference between the clinical applications is a result of the difference in total utilization costs, which is influenced by the time required for all services, which increases the OR's expenses and personnel fees.

3.4. Sensitivity analysis

The addition of extra physicians in both the optimized clinical application and the common clinical application results in an increase in personnel fees which increases the total utilization costs. However, the reimbursement rates for both clinical applications remain the same. In the optimized clinical application, the personnel fees increase by $293.72, totaling $1,381.24 (Figure 10). This results in a reduction of the cost-reimbursement difference, amounting to $6,263.32. Similarly, in the common clinical application, the personnel fees increase by $433.24, bringing the total to $1,826.30. Consequently, the cost-reimbursement difference is reduced to -$189.44.

The personnel fees in the optimized clinical application are $445.07 less than in the standard clinical application. This difference can be attributed to the shorter duration of sub-activities in the optimized clinical application, which led to a reduction in personnel compensation compared to the personnel fees for the clinical application. When comparing the cost-reimbursement difference between the two clinical applications, we observe that the cost-reimbursement difference for the optimized clinical application is $6,425.76 (approximately 32 times) greater than the cost-reimbursement difference for the common clinical application. Additionally, in the common clinical application, the increase in personnel fees contributes to a discrepancy between Medicare reimbursement and total utilization costs.

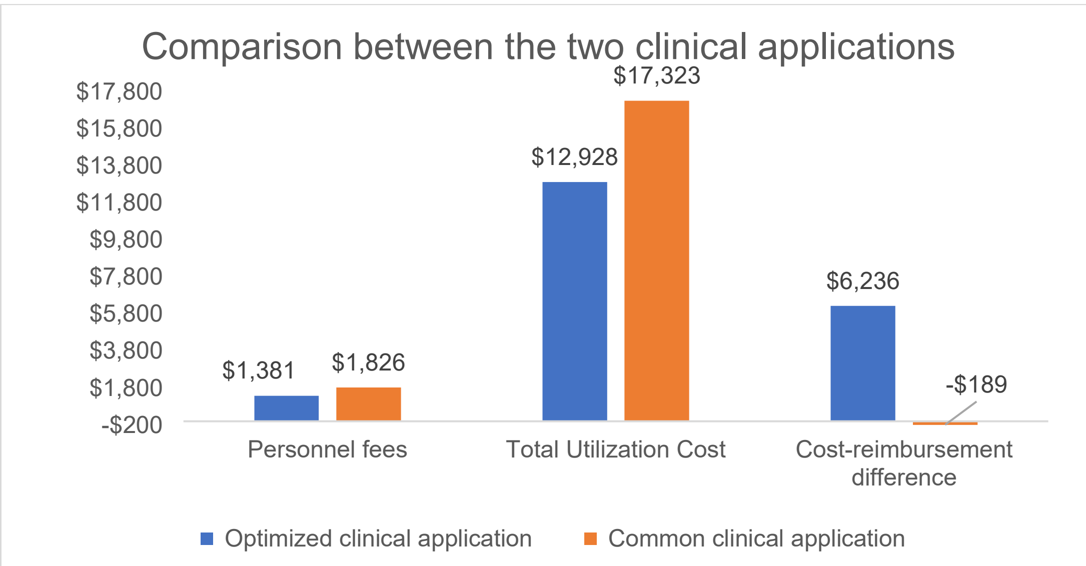


Figure 10 Results of the sensitivity analysis

The second sensitivity analysis that we performed was regarding the number of patients per year. According to Solodkiy et al. (2022), we estimated the number of patients per year to be 32. When we increase the number of patients to 100, we observe changes in the clinical application's cost analysis. Specifically, the total equipment cost per patient decreases by $1,665, leading to a reduced utilization cost per patient of approximately $10,970 (Figure 11). In addition, the equipment cost per patient per year decreases to $392 as the number of patients increases to 200 which leads to a $2,056 reduction in the cost of equipment per patient (Table 10). In this scenario, the cost-reimbursement difference peaks at $8,586, with $2,056 more than in the scenario with 32 patients per year. Therefore, the decrease in equipment costs per patient per year exemplifies the benefit of economies of scale, in which higher patient volumes result in lower per-patient equipment expenses.

Table 10 The equipment cost per patient

Number of patients per year	Equipment cost per patient
32	$2,448.00
50	$1,566.40
100	$783.00
150	$522.00
200	$392.00

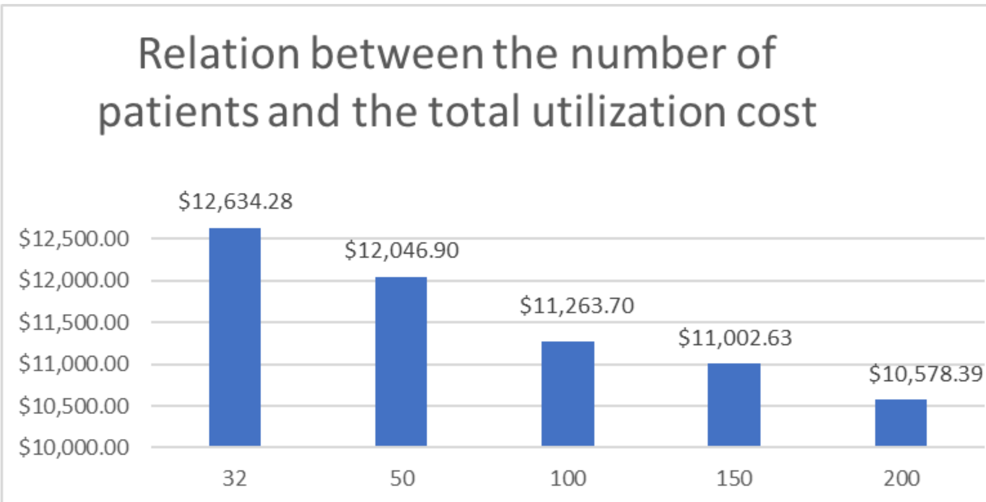


Figure 11 Relation between equipment cost and number of patients per year

In our sensitivity analysis, we examined the relationship between indirect costs and total utilization costs, as illustrated in Figure 12. Initially, we assumed that 20% of the equipment cost represented indirect costs (Alyamani et al., 2021). To determine the effect of indirect costs for the optimized clinical application, we increased the percentage by 10% intervals up to 90%. As the indirect costs increased from 20% to 30%, the total utilization costs increased by roughly 7%. In addition, when indirect costs reached 90% of the cost of the equipment, the total utilization costs increased by nearly 13%. These results indicate that indirect costs have a substantial impact on utilization costs. It is essential to note that the scale of indirect costs can vary between hospitals based on how each institution accounts for and allocates indirect expenses.

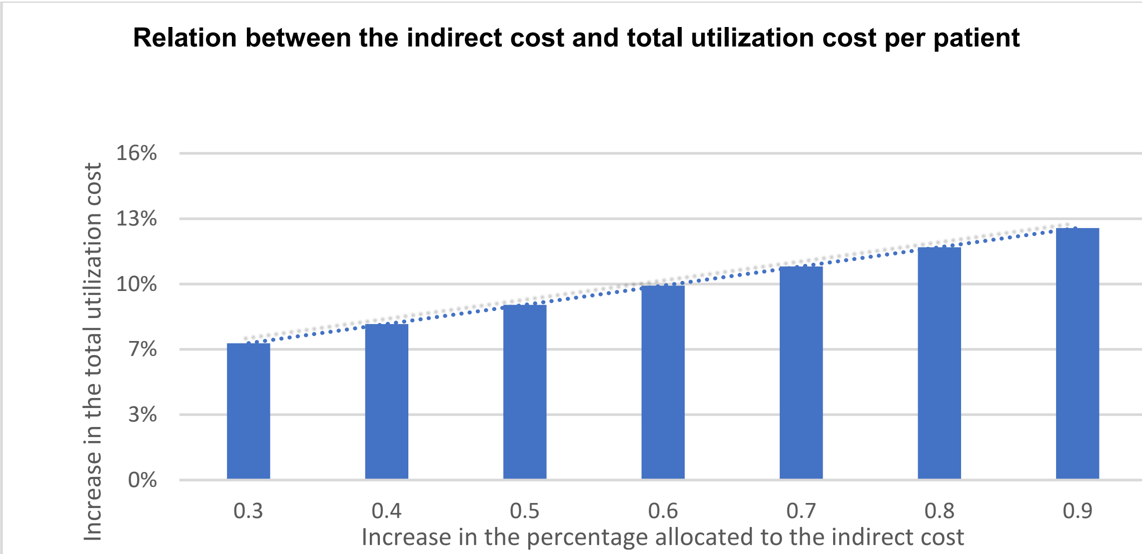


Figure 12 Relation between the indirect cost and total utilization cost

In conclusion, using the spreadsheet simulation, we identified that the overall cost for the optimized clinical application has decreased by 25% and the reimbursement increased by 12%. Moreover, the time of patients under anesthesia has decreased by 85.8 minutes which decreases the risk of patients developing adverse events. Additionally, we performed a sensitivity analysis to investigate how indirect costs influence the total utilization cost and how adding extra personnel and having more patients per year influence the cost-reimbursement difference.

4. Discussions and Conclusion

The declining use of brachytherapy in the United States is caused by multiple factors, including unfavorable reimbursement for the procedure (Andring et al., 2021). Our objective was to identify areas for improvement in the cost-reimbursement difference for the clinical application of HDR brachytherapy for prostate cancer in the United States.

We investigated how clinical applications are performed in the United States, analyzed the reimbursement policies and rates in the United States, and determined the total utilization cost and cost-reimbursement discrepancies. Our economic evaluation revealed that the total cost for the common clinical application was $16,890.06, whereas the total cost for the optimized clinical application decreased by approximately 25%, reaching a maximum of $12,634.28. Medicare reimburses the most common clinical application at $17,133.86, while the optimized clinical application is reimbursed at $19,164.32, which is approximately 12% more. This resulted in ~~substantial~~ increase in the cost-reimbursement difference for the optimized clinical application. Moreover, the time of patient under anesthesia decreased by 85.8 minutes (32%) for the optimized clinical application compared to the common clinical application.

One of the potential solutions to increase utilization of brachytherapy for prostate cancer suggested by Mulherkar et al. (2021) was to enhance Medicare reimbursement policies in coordination with value-based brachytherapy practices to allow for appropriate compensation for the treatments. Our results of the comparison between the two clinical applications showed that the optimized clinical application is a relevant alternative because it decreased the cost by ~~25%~~ and the reimbursement increased by ~~12%~~. There was no discrepancy between the costs of activities and Medicare reimbursement for all brachytherapy-related activities for the optimized clinical application. The only service that was not fully reimbursable was the clinical consultation with a new patient which resulted in a loss of $21.28. The consultation fee for new patients is set at a standard rate of reimbursement for the radiation oncology department. As a result, it is possible to improve the cost-reimbursement difference by optimizing billing by negotiating with insurance companies for higher reimbursement rates.

In our optimized clinical application, the dosimetrists delineate the tumor and organs at risk, resulting in a decrease in personnel fees and total cost. This strategy aligns with the study by Laviana et al. (2015), which showed that reducing the workload of radiation oncologists can lower the overall cost. Furthermore, the time-driven activity-based costing analysis by Dutta et al. (2018) concluded that excluding operating room (OR) costs, personnel fees contribute significantly to the higher total costs of brachytherapy treatments. However, our results highlight a different scenario for the optimized clinical application. After the cost of the operating room, equipment costs account for most utilization expenses. A possible explanation for that is that Dutta et al. (2018) assigns more personnel for each sub activity while we selected one performer per sub activity. However, one way to decrease the equipment cost per patient is to increase the number of patients per year, as revealed in the sensitivity analysis.

Mulherkar et al. (2021) argue that the discrepancy between the total utilization cost and the Medicare reimbursement decreases the utilization of HDR brachytherapy for prostate cancer. In our research, the cost-reimbursement difference for the optimized clinical application was positive and higher than for the common clinical application. In our research, we assumed that there was one main performer for each sub-activity. However, by increasing the number of personnel in the sensitivity analysis, we observed that the cost-reimbursement difference for the common clinical application became negative, while for the optimized clinical application it was still positive and almost 33 times higher. These findings highlight the necessity of implementing strategies that increase the cost-reimbursement difference. Therefore, our study contributes to the existing literature by identifying specific components that influence cost-reimbursement differences and proposing an optimized clinical application that overcomes the discrepancy between the clinical applications.

Mitchell et al. (2019) state that reimbursement rates influence healthcare providers treatment decisions. The cost-reimbursement difference improvement of the optimized clinical application may encourage healthcare providers to adopt the optimized approach for treating patients. Moreover, the optimized clinical application can increase patient safety because it decreases the time under anesthesia. Chen et al. (2021) conclude that by reducing anesthesia time and the number of needles, the patient may perceive fewer acute side effects. Therefore, the optimized clinical application has the potential to increase the accessibility and affordability of HDR brachytherapy for prostate cancer patients that will lead to a societal benefit.

This research has some limitations, which must be considered when interpreting the results. Firstly, the time considered in the calculation of total utilization costs for the optimized clinical application is an assumption for treatment preparation. Therefore, we recommend collecting additional information about the time and evaluating it with a tool that can accommodate new input values.

Secondly, the survey results do not indicate how many personnel are present. In our analysis, we selected one performer per step. In practice, they may be more personnel involved in each step which can cause an underestimation of personnel fees. Therefore, we recommend investigating the number of involved personnel.

Thirdly, with the new alternative payment model (APM) proposed by the Centers for Medicare & Medicaid Services (CMS), reimbursement is fixed for radiation oncology physicians and clinics. Our research is based on 2023 Medicare reimbursements rates which includes different payments in fraction scheduling, imaging modalities, or treatment techniques during the preoperative treatment planning. When the new model is implemented, it is necessary to review the reimbursement policies.

Moreover, literature is used to derive the value of indirect costs. However, hospitals may account for indirect costs differently. Therefore, we recommend speaking with the users and collecting more precise input values.

Regarding these limitations, it is essential to interpret the findings with consideration of the restrictions. Future research should aim to address these limitations by refining assumptions and collecting more comprehensive data. In addition, it would be beneficial to conduct additional research comparing the cost-reimbursement differences between the optimized clinical application for HDR brachytherapy and external beam therapies for prostate cancer. This comparative analysis can provide insights into different treatment options' financial implications, allowing for informed decision-making and resource allocation in clinical practice.

In conclusion, we proposed an alternative clinical application HDR Brachytherapy for prostate cancer that is better reimbursed according to the USA reimbursement policies. Significant cost reduction and increased reimbursement highlight the financial benefits of this clinical application, which makes it potential an attractive choice for healthcare providers once Elekta has also advanced their portfolio in this direction. In addition to financial benefits, the optimized clinical application improves patient safety and treatment precision. Therefore, the optimized clinical implementation has the potential to improve HDR brachytherapy practice, to the benefit of patients and healthcare providers.

4. References

Alyamani, N., Song, J., Van Katwyk, S., Wodchis, W. P., Renaud, J., Haddad, A., MacPherson, M., & Gaudet, M. (2021). Cost–Utility Analysis of Radiation Treatment Modalities for Intermediate-Risk Prostate Cancer. *Current Oncology*, *28*(4), 2385–2398. https://doi.org/10.3390/curroncol28040219

Andring, L., Yoder, A., Pezzi, T. A., Tang, C., Kumar, R., Mahmood, U., & Walker, G. V. (2021). PSA: Declining utilization of prostate brachytherapy. *Brachytherapy*, *21*(1), 6–11. https://doi.org/10.1016/j.brachy.2021.07.004

Brachytherapy for Cancer. (2019, January 29). National Cancer Institute. https://www.cancer.gov/about-cancer/treatment/types/radiation-therapy/brachytherapy

Cancer today. (n.d.). https://gco.iarc.fr/today/online-analysis-pie?v=2020&mode=cancer&mode_population=continents&population=900&populations=900&key=total&sex=1&cancer=39&type=2&statistic=5&prevalence=1&population_group=0&ages_group%5B%5D=0&ages_group%5B%5D=17&nb_items=7&group_cancer=1&include_nmsc=1&include_nmsc_other=1&half_pie=0&donut=0

Chen, Z., Zhou, L., Jiang, S., & Haddix, A. C. (2020). Identifying Options of Best Value: Use of Economic Evaluation in Public Health. *China CDC Weekly*, *2*(5), 75–78. https://doi.org/10.46234/ccdcw2020.021

Coders, M. B. A. (2023). Understanding Basics of Ambulatory Coding. *Read Our Latest Medical Billing and Coding Blogs*. https://www.medicalbillersandcoders.com/blog/basics-of-ambulatory-coding/

Cooper, D. R., & Schindler, P. S. (2013). *Business Research Methods*. McGraw-Hill Education.

Crook, J., Marbán, M., & Batchelar, D. (2020). HDR Prostate Brachytherapy. *Seminars in Radiation Oncology*, *30*(1), 49–60. https://doi.org/10.1016/j.semradonc.2019.08.003

Cruz-Martínez, R. R. (2022, September 8). *Practice guide: Setting up your systematic search strategy*. Zenodo. https://doi.org/10.5281/zenodo.7062727

D'Souza, D., Perdrizet, J., Skliarenko, J., Ang, M. H., Barbera, L., Ravi, A., Gutierrez, E., Tanderup, K., Warde, P., Chan, K. M., Isaranuwatchai, W., & Milosevic, M. (2017). A Cost-Utility Analysis Comparing MR-Guided Brachytherapy to Standard 2D Brachytherapy for Patients With Locally Advanced Cervical Cancer in Ontario, Canada. *International Journal of Radiation Oncology Biology Physics*. https://doi.org/10.1016/j.ijrobp.2017.06.558

Dutta, S., Bauer-Nilsen, K., Sanders, J. L., Trifiletti, D. M., Libby, B., Lash, D. H., Lain, M., Christodoulou, D., Hodge, C., & Showalter, T. N. (2018). Time-driven activity-based cost comparison of prostate cancer brachytherapy and intensity-modulated radiation therapy. *Brachytherapy*, *17*(3), 556–563. https://doi.org/10.1016/j.brachy.2018.01.013

Eastham, J. A., Auffenberg, G., Barocas, D. A., Chou, R., Crispino, T., Davis, J. M., Eggener, S. E., Horwitz, E. M., Kane, C. J., Kirkby, E., Lin, D. W., McBride, S., Morgans, A. K., Pierorazio, P. M., Rodrigues, G., Wong, W., & Boorjian, S. A. (2022). Clinically Localized Prostate Cancer: AUA/ASTRO Guideline. Part III: Principles of Radiation and Future Directions. *The Journal of Urology*, *208*(1), 26–33. https://doi.org/10.1097/ju.0000000000002759

Enhance Health. (2023, May 19). *How Much Does An MRI Cost Without Insurance In 2023? - Enhance Health*. https://enhancehealth.com/how-much-does-an-mri-cost-without-insurance/

Guthier, C. V., Orio, P. F., Buzurovic, I., & Cormack, R. A. (2021). Knowledge-based inverse treatment planning for low-dose-rate prostate brachytherapy. *Medical Physics*, *48*(5), 2108–2117. https://doi.org/10.1002/mp.14775

Harkenrider, M. M., Albuquerque, K., Brown, D. S., Kamrava, M., King, M., Mourtada, F., Orio, P. F., Patel, R. P., Price, M., Rassiah, P., Solanki, A. A., Small, W., & Schechter, N. R. (2021a). ACR–ABS–ASTRO practice parameter for the performance of radionuclide-based high-dose-rate brachytherapy. *Brachytherapy*. https://doi.org/10.1016/j.brachy.2021.08.009

Heerkens, H. (2015). mpsm intro kort on Vimeo. https://vimeo.com/showcase/2938606/video/101271071

Johnson, S., Pan, A., Sun, G. Y., Freed, A., Stokes, J., Bornstein, R., Witkowski, M. J., Li, L., Ford, J. W., Howard, C. J., Sedensky, M. M., & Morgan, P. B. (2019). Relevance of experimental paradigms of anesthesia induced neurotoxicity in the mouse. *PLOS ONE*, *14*(3), e0213543. https://doi.org/10.1371/journal.pone.0213543

Laviana, A. A., Ilg, A. M., Veruttipong, D., Tan, H., Burke, M. G., Niedzwiecki, D., Kupelian, P. A., King, C., Steinberg, M. L., Kundavaram, C., Kamrava, M., Kaplan, A., Moriarity, A. K., Hsu, W., Margolis, D., Hu, J. C., & Saigal, C. S. (2015). Utilizing time-driven activity-based costing to understand the short- and long-term costs of treating localized, low-risk prostate cancer. *Cancer*, *122*(3), 447–455. https://doi.org/10.1002/cncr.29743

Li, B., Hirata, E., Trejo, J. M., Garcia, B., Chang, B., Malhotra, S., Ning, M., & Sarria, G. J. (2023). Exploring the Cost of Radiation Therapy Delivery for Locally Advanced Cervical Cancer in a Public and a Private Center in Latin America Using Time-Driven Activity-Based Costing. *International Journal of Radiation Oncology Biology Physics*, *115*(5), 1205–1216. https://doi.org/10.1016/j.ijrobp.2022.11.046

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic Inquiry. SAGE.

Mason, J. (2018). Qualitative Researching. SAGE Publications Limited.

Medicare NCCI Policy Manual | CMS. (n.d.). https://www.cms.gov/medicare-medicaid-coordination/national-correct-coding-initiative-ncci/ncci-medicare/medicare-ncci-policy-manual

Mitchell, A. P., Rotter, J. S., Patel, E., Richardson, D., Wheeler, S. B., Basch, E., & Goldstein, D. A. (2019). Association Between Reimbursement Incentives and Physician Practice in Oncology. *JAMA Oncology*, *5*(6), 893. https://doi.org/10.1001/jamaoncol.2018.6196

Parikh, N., Lee, P., Raman, S. S., Cao, M., Lamb, J., Tyran, M., Chin, W., Gilchrist, T., Agazaryan, N., Mittauer, K., Steinberg, M. L., & Raldow, A. C. (2020). Time-Driven Activity-Based Costing Comparison of CT-Guided Versus MR-Guided SBRT. *JCO Oncology Practice*, *16*(11), e1378–e1385. https://doi.org/10.1200/jop.19.00605

Physician Assistants. (2023, April 25). https://www.bls.gov/oes/current/oes291071.htm

Reimbursement - Practice Management Resources - American Society for Radiation Oncology (ASTRO) - American Society for Radiation Oncology (ASTRO). (n.d.). ASTRO. https://www.astro.org/Daily-Practice/Reimbursement/Practice-Management-Resources

Rice, T., Rosenau, P., Unruh, L. Y., & Barnes, A. J. (2021). *Health Systems in Transition: USA, Second Edition*. University of Toronto Press.

Rodin, D., Chien, A. T., Ellimoottil, C., Nguyen, P. L., Kakani, P., Mossanen, M., Rosenthal, M. B., Landrum, M. B., & Sinaiko, A. D. (2020). Physician and facility drivers of spending variation in locoregional prostate cancer. *Cancer*. https://doi.org/10.1002/cncr.32719

Schad, M. D., Patel, A., Glaser, S., Balasubramani, G. K., Showalter, T. N., Beriwal, S., & Vargo, J. J. (2020). Declining brachytherapy utilization for cervical cancer patients - Have we reversed the trend? *Gynecologic Oncology*, *156*(3), 583–590. https://doi.org/10.1016/j.ygyno.2019.12.032

Sekhoacha, M., Riet, K., Motloung, P. A., Gumenku, L., Adegoke, A., & Mashele, S. S. (2022). Prostate Cancer Review: Genetics, Diagnosis, Treatment Options, and Alternative Approaches. *Molecules*, *27*(17), 5730. https://doi.org/10.3390/molecules27175730

Sekhoacha, M., Riet, K., Motloung, P. A., Gumenku, L., Adegoke, A., & Mashele, S. S. (2022c). Prostate Cancer Review: Genetics, Diagnosis, Treatment Options, and Alternative Approaches. *Molecules*, *27*(17), 5730. https://doi.org/10.3390/molecules27175730

Smith, T., Evans, J., Moriel, K., Tihista, M. C., Bacak, C., Dunn, J., Rajani, R., & Childs, B. R. (2022). Cost of OR Time is $46.04 per Minute. *Journal of Orthopaedic Business*, *2*(4), 10–13. https://doi.org/10.55576/job.v2i4.23

Sturdza, A. E., Stephanides, M., Jurgenliemk-Schulz, I., Eriksen, J. G., Benstead, K., Hoskin, P., Vlad, S., Escande, A., Corradini, S., Knoth, J., Westerveld, H., Tagliaferri, L., Najari-Jamali, D., Konat, K., Plesinac, V., Tan, L. T., Nout, R., Strnad, V., Niehoff, P., . . . Kamrava, M. (2022). Brachytherapy training survey among radiation oncology residents in Europe. *Radiotherapy and Oncology*, *177*, 172–178. https://doi.org/10.1016/j.radonc.2022.10.030

WCRF International. (2022, April 14). *Worldwide cancer data | World Cancer Research Fund International*. https://www.wcrf.org/cancer-trends/worldwide-cancer-data/

Williams, V. M., Kahn, J. M., Thaker, N. G., Beriwal, S., Nguyen, P. L., Arthur, D. W., Petereit, D. G., & Dyer, B. A. (2021). The Case for Brachytherapy: Why It Deserves a Renaissance. *Advances in Radiation Oncology*, *6*(2), 100605. https://doi.org/10.1016/j.adro.2020.10.018

Zhang, Y., Lei, Y., Qiu, R. L., Wang, T., Wang, H., Jani, A. B., Curran, W. J., Patel, P., Liu, T., & Yang, X. (2020). Multi-needle Localization with Attention U-Net in US-guided HDR Prostate Brachytherapy. *Medical Physics*, *47*(7), 2735–2745. https://doi.org/10.1002/mp.14128