Original paper

A comparative cost-benefit analysis of electronic brachytherapy vs. high-dose-rate iridium-192 for exclusive vaginal cuff treatment in post-operative endometrial cancer

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Abstract

Purpose: To compare the economic and dosimetric aspects of electronic brachytherapy (eBT) and high-dose-rate (HDR) iridium-192 (^{192}Ir) brachytherapy for exclusive vaginal cuff treatment in post-operative endometrial cancer patients.

Material and methods: This retrospective observational study was conducted among 115 patients treated with eBT and 70 patients treated with HDR ^{192}Ir between 2019 and 2023 at two institutions. All patients underwent 3 fractions of 7 Gy prescribed to a uniform target volume. Dosimetric parameters, including D_{90}, V_{150}, and V_{200} for high-risk clinical target volume (HR-CTV) as well as D_{2cc}, D_{1cc}, and $D_{0.1cc}$ for organs at risk (OARs), such as bladder, rectum, and sigmoid colon, were compared. Economic analysis focused solely on cost differences related to source replacement and maintenance, as all other procedural factors (i.e., personnel, clinical workflow, and logistics) were identical for both modalities. The cost of bunker was not considered in the analysis.

Results: Dosimetric analysis revealed comparable target volume coverage between eBT and HDR ^{192}Ir. The economic evaluation was focused on cost differences and their relative contributions. The relative average cost per patient under these assumptions was 18.4% lower for eBT (€273.9) than for HDR ^{192}Ir, based on Spanish pricing, largely due to differences in source-related expenditures.

Conclusions: While ^{192}Ir HDR remains the standard in brachytherapy due to its versatility, eBT presents a cost-benefit alternative for exclusive vaginal cuff treatments, particularly in settings where infrastructure limitations restrict isotope-based brachytherapy. These findings support the complementary role of eBT in clinical practice, optimizing resource allocation without compromising dosimetric quality.

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Key words: endometrial cancer, brachytherapy, electronic brachytherapy, economic evaluation, HDR ^{192}Ir, cost-benefit analysis, dosimetric parameters.

Purpose

Endometrial cancer ranks among the most prevalent gynecologic malignancies worldwide, with its incidence rising along with increasing life expectancy, obesity, and metabolic disorders. According to the GLOBOCAN 2018 estimates, it remains a significant cause of cancer-related morbidity and mortality in developed regions [1].

Standard management typically involves total hysterectomy with bilateral salpingo-oophorectomy, occasionally together with lymph node assessment, followed by radiotherapy in selected cases to reduce loco-regional recurrence [2, 3]. For patients with low- to intermediate-risk disease, post-operative vaginal brachytherapy demonstrates excellent local control while maintaining favorable toxicity profiles [4, 5].

High-dose-rate (HDR) brachytherapy using an iridium-192 (^{192}Ir) source has traditionally been the modality of choice, supported by robust clinical data, well-estab-

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lished protocols, and widespread availability [6]. However, technical advances have led to the development of electronic brachytherapy (eBT) that produces low-energy X-rays *in situ*. This technology avoids the need for transporting, storing, and disposing of radioactive isotopes, potentially offering advantages in terms of radiation safety and infrastructure requirements [7, 8]. While eBT has gained traction in early-stage breast cancer and dermatologic indications, its application in gynecologic malignancies has been limited [9]. Early evidence, however, suggests comparable dosimetric and clinical outcomes between eBT and ^{192}Ir HDR for endometrial cancer, prompting interest in its broader adoption [10, 11]. From an economic perspective, each approach incurs distinct costs and benefits. Conventional HDR brachytherapy with ^{192}Ir may require dedicated bunkers, specialized source handling, and periodic source replacements, thus incurring ongoing expenses [12]. In contrast, eBT involves a higher upfront equipment cost but eliminates radioactive source replenishment, and may allow treatments in rooms with less extensive shielding [7, 9]. Where clinical effectiveness appears similar, it becomes critical to assess cost differentials, factoring in setup expenses, maintenance contracts, consumable usage, and potential logistical efficiency [13]. Moreover, as healthcare systems increasingly focus on value-based care, delivering high-quality treatments at sustainable costs remains a top priority [14].

In this study, we presented a cost-benefit analysis comparing exclusive ^{192}Ir brachytherapy and eBT in patients with endometrial cancer. Our primary goal was to quantify the financial implications of each modality, encompassing acquisition, maintenance, and procedural expenses under the assumption of equivalent oncologic outcomes. By highlighting the key drivers of the costs and possible areas for optimization, we aimed to provide clinicians, hospital administrators, and policy-makers with evidence-based insights to guide technology selection and resource allocation. Ultimately, we hoped this analysis would inform strategies to maintain or enhance clinical efficacy while minimizing economic burdens for a growing population of patients requiring radiotherapeutic management of endometrial cancer [11].

In addition to the cost-benefit evaluation, this study provided a detailed dosimetric comparison between HDR ^{192}Ir and electronic brachytherapy modalities. Although previous investigations have indicated comparable dosimetric profiles [11], such an analysis would strengthen the clinical relevance of the findings, demonstrating more holistic approach to technology selection in the management of post-operative endometrial cancer.

Material and methods

This retrospective observational study analyzed the cost-benefit of exclusive brachytherapy in endometrial cancer patients treated in two Spanish centers between 2019 and 2023. All patients included in this analysis had completed treatment before the evaluation period. The primary objective was to compare the economic and dosimetric outcomes of eBT and HDR ^{192}Ir brachytherapy, specifically focusing on patients treated exclusively with brachytherapy and without supplementary external beam radiotherapy (EBRT), to maintain consistency in the treatment modality. One center is equipped with HDR ^{192}Ir unit, while the other uses eBT technology.

A total of 70 patients were treated with ^{192}Ir HDR brachytherapy, and 115 patients received eBT. Inclusion criteria comprised type I FIGO stage IA endometrial cancer with risk factors, type I FIGO stage IB, and, especially, type II FIGO stage II in patients whose comorbidities precluded EBRT (Table 1). Baseline clinical and tumor characteristics (i.e., FIGO stage, histologic grade, and lymphovascular invasion) were compared between eBT and ^{192}Ir groups.

Regarding brachytherapy planning and delivery for vaginal cuff irradiation, each patient received 3 fractions of 7 Gy, yielding a total dose of 21 Gy prescribed at a 5 mm depth from the applicator surface, in accordance with established clinical guidelines for adjuvant treatment in endometrial cancer [4]. Two treatment modalities were employed. In the ^{192}Ir HDR approach, treatments were planned using Oncentra Brachy system (version 4.6.3, Elekta, Stockholm, Sweden), and a radioactive ^{192}Ir source with a half-life of approximately 74 days was utilized, undergoing quarterly replacements. The center, which uses HDR ^{192}Ir equipment, is treating an average of over 220 patients annually, performing more than 740 sessions across 17 different locations. Alternatively, eBT was delivered using BrachyVision system (Varian Medical Systems, Palo Alto, CA), coupled with a 50 kVp X-ray source (Xoft Axxent). The eBT unit produces low-energy X-rays, enabling treatments to be delivered in minimally shielded procedure rooms, thereby eliminating the need for specialized radiation shielding.

Staff resources required for both treatment modalities, HDR ^{192}Ir and eBT, are quite similar. Both modalities require trained professionals for patient setup, treatment delivery, and monitoring during the procedure. Tasks performed by medical physicists, radiation oncologists, and other clinical staff are comparable in both approaches, as both involve precision placement and radiation dose delivery, although differing in technology.

Regarding commissioning and QA time, the procedures are also similar. Both modalities require initial commissioning and regular QA to ensure optimal treatment delivery. Processes involved in both types of brachyther-

Table 1. Tumor characteristics in patients treated with electronic brachytherapy (eBT) vs. high-dose-rate (HDR) iridium-192 (^{192}Ir)

Characteristic	^{192}Ir (n = 70)	eBT (n = 115)
Endometrioid histology (type I)	88%	89%
Lymphovascular invasion	19%	15%
Moderately differentiated (grade 2)	60%	65%
Myometrial invasion > 50%	27%	25%
FIGO stage IA	78%	69%
FIGO stage IB	21%	29%
FIGO stage II	1%	2%

Table 2. Planning parameters for vaginal cuff brachytherapy

Parameter	Center A (^{192}Ir)	Center B (eBT)
CT slice thickness (mm)	2-3	2-3
Applicator diameters (cm)	2.5/3/3.5	2.5/3/3.5
Prescription depth from applicator (mm)	5	5
Number of fractions	3	3
Dose per fraction (Gy)	7	7
Total prescribed dose (Gy)	21	21
Planning software	Oncentra Brachy	BrachyVision

apy are analogous, including source calibration, verification of treatment plans, and system maintenance.

The eBT sources require replacement every 750 minutes of clinical use, corresponding to a cost per patient based on an average treatment duration of approximately 5 minutes per session. Dose optimization was achieved by adjusting dwell times along the vaginal cylinder to ensure homogeneous coverage. The cost of each source replacement was included in the cost per minute (the source has an autonomy of 750 minutes, therefore its cost is divided by the total number of minutes and multiplied by the minutes used for the endometrial cases analyzed) of treatment in the case of eBT [4]. Prior to treatment, patients underwent computed tomography (CT) simulation in a supine position with a slice thickness of 2-3 mm. CT images facilitated precise delineation of clinical target volume (CTV) defined as the upper 3-5 cm of the vaginal cuff and of organs at risk (OARs), such as the bladder, rectum, and sigmoid colon (Table 2) [15]. Dose distributions were optimized to deliver 7 Gy per fraction to 5 mm from the CTV while minimizing exposure to OARs, with key dosimetric parameters, including D_{2cc}, D_{1cc}, and $D_{0.1cc}$ for the bladder, rectum, and sigmoid systematically recorded (Table 2). Each treatment plan was reviewed by a radiation oncologist and a medical physicist to ensure adherence to dose constraints [16, 17]. Moreover, comprehensive quality assurance procedures were implemented. For HDR ^{192}Ir brachytherapy, source calibration, dwell times, dwell position tests, and periodic activity checks following each source replacement were verified, whereas for eBT, X-ray source output was confirmed using calibrated detectors prior to each treatment fraction [18].

An activity-based cost analysis was conducted from the hospital's perspective to determine the total cost of each brachytherapy modality by incorporating all relevant expense components across the centers. Capital equipment expenditures, including acquisition of brachytherapy units (HDR afterloader and eBT generator) were annualized over their respective lifespans using a straight-line depreciation model, with one approach assuming an eight-year lifespan and another allocating depreciation over a standard equipment lifespan of five to ten years in accordance with center-specific financial policies. Source replacement and maintenance costs were subsequently evaluated, with HDR ^{192}Ir necessitating quarterly radioactive source replacement, encompassing procurement, shipping, and disposal fees, while eBT requiring annual service contracts for the electronic source, source replacement every 750 minutes of clinical use, and routine maintenance. Overhead and infrastructure costs, such as differential shielding requirements between HDR ^{192}Ir and eBT procedures, were not included in the analysis due to variability in local construction costs and broader clinical use of ^{192}Ir bunkers (as discussed later in the manuscript), whereas eBT procedures can be performed in standard rooms with minimal additional shielding [12]. Consumable costs per session, with various items, such as sterile applicator covers and lubricants, were estimated, with ancillary operational costs (e.g., electricity consumption and minor disposables) assumed equivalent between both techniques, unless center-specific data indicated otherwise. Personnel costs calculated based on standardized salary data from the Spanish National Health System were considered identical for both modalities, given the consistent treatment schedule (3 fractions of 7 Gy) and utilization of equivalent staff resources, thereby negating additional labor cost differentials. Global cost figures for each center were derived by summing annualized equipment depreciation, source replacement and maintenance, infrastructure, and consumable costs, and then normalizing these totals to the overall number of brachytherapy sessions performed annually across departments in all brachytherapy procedures. The resulting per-session cost was multiplied by 3 to yield the cost per patient. Both modalities were implemented using established systems. The economic evaluation of this study focused exclusively on cost differences associated with different equipment used in each modality. Specifically, both techniques involved the same number of medical consultations, equivalent time allocation for medical physics assessments and quality control, and identical physician supervision, ensuring uniformity in all procedural aspects.

Additionally, vaginal cylinders of various diameters were utilized to accommodate patient anatomy, with applicators sterilized and prepared per each institution's standard operating procedures. This comprehensive cost evaluation integrated capital investment, operational expenditures, and personnel costs, to provide a detailed economic assessment of HDR ^{192}Ir vs. eBT, thereby demonstrating resource allocation and decision-making processes in clinical practice [19, 20].

Results

The costs were analyzed across several categories, including staff, equipment, and operating expenses, with values provided in both EUR and USD. The key cost components, such as acquisition and depreciation, source replacement and maintenance as well as infrastructure and quality assurance, are summarized in Table 3.

The primary economic differentiators between the two techniques were the costs associated with equipment usage, including source replacement and maintenance expenses. The distribution of total sessions and exclusive endometrial brachytherapy sessions per year for both mo-

Table 3. Cost comparison between high-dose-rate (HDR) iridium-192 (^{192}Ir) and electronic brachytherapy (eBT) for exclusive endometrial brachytherapy (applicable to Spain under current economic conditions and assumptions of this work, with exchange rate as of March 2025: 1 EUR = 1.1160 USD)

Cost item/parameter	^{192}Ir (EUR)	^{192}Ir (USD)	eBT (EUR)	eBT (USD)	Difference (eBT vs. ^{192}Ir) (EUR)	Difference (eBT vs. ^{192}Ir) (USD)
I. Staff costs (per patient)[1]	330.0	368.3	330.0	368.3	0.0	0.0
II. Equipment costs						
A) Acquisition and depreciation (per patient)[2]	344.5	384.5	299.5	334.2	–45	–50.3
B) Source replacement and maintenance (per patient)	565.2	631.4	336.3	375.6	–228.9	–255.8
C) Infrastructure, TPS, and QA (per patient)	100.0	111.6	100.0	111.6	0.0	0.0
III. Operating costs						
Consumables total (3 sessions) (per patient)[3]	150.0	167.4	150.0	167.4	0.0	0.0
IV. Estimated total cost under assumptions of this work (per patient)[4]	1,489.7	1,662.5	1,215.8	1,356.8	–273.9 (–18.4%)	–305.7 (–18.4%)

*[1] Identical staff (medical consultations, physics support, and physician supervision) for both modalities; [2] Acquisition and depreciation (per patient) refers to equipment acquisition and depreciation costs calculated based on clinical usage per patient. This category includes the initial investment made when purchasing the equipment (either HDR ^{192}Ir or eBT), amortized over its expected lifespan and clinical utilization frequency, resulting in an estimated per-patient cost reflecting equipment depreciation; [3] Covers all clinical consumables, except for the radiation source (applicators, covers, lubricants, etc.), assumed identical for both HDR ^{192}Ir and eBT; [4] Sum of staff costs (I) + equipment costs (II) + operating costs (III); *Note – personnel costs are based on average salary data from the Spanish National Health System [21]. Costs are applicable to Spain under current economic conditions*

dalities is presented in Table 4, with the cost per session derived from source replacement and maintenance expenses.

For the purpose of this cost-benefit evaluation, we assumed there would be no significant differences in dosimetric outcomes between eBT and ^{192}Ir HDR brachytherapy utilization in patients with endometrial cancer [11]. This assumption was supported by studies indicating that eBT provides comparable efficacy and safety profiles to HDR ^{192}Ir brachytherapy for vaginal cuff irradiation, with similar rates of local recurrence and treatment-related toxicities [7, 9]. As such, any cost differentials observed in this analysis primarily reflected differences in equipment, source replacement, and maintenance, rather than variations in clinical efficacy or complication rates.

The dosimetric comparison between eBT and ^{192}Ir HDR brachytherapy is summarized in Table 5. All values are expressed as a percentage of the prescribed dose (7 Gy per fraction), while mean values, standard deviations (SD), and ranges are presented for each organ at risk (OAR) parameter, reflecting the distribution of doses across all patients in each group, with independent samples *t*-test employed.

Overall, the target coverage was comparable between the two modalities (data not shown), and OARs doses demonstrated slight variations favoring one technique or the other, depending on the specific parameter. For instance, eBT yielded lower mean bladder D_{2cc}, but slightly higher bladder $D_{0.1cc}$, whereas rectal and sigmoid parameters exhibited similar trends between eBT and ^{192}Ir HDR, but not statistically significant.

These dosimetric findings align with previously published reports [11], suggesting that eBT can achieve dose distributions comparable to ^{192}Ir HDR brachytherapy, while maintaining acceptable OARs constraints for post-operative endometrial cancer treatments.

Discussion

The results of this study confirm that eBT offers a viable alternative for treating post-operative endometrial

Table 4. Annual distribution of brachytherapy sessions for iridium-192 (^{192}Ir) and electronic brachytherapy (eBT)

^{192}Ir	2019	2020	2021	2022	2023
Total patient sessions	646	741	767	706	848
Exclusive endometrial patients	12	16	11	15	16
Exclusive endometrial sessions	36	48	33	45	48
eBT	**2019**	**2020**	**2021**	**2022**	**2023**
Total patient sessions	361	375	377	354	388
Exclusive endometrial patients	20	25	24	19	27
Exclusive endometrial sessions	60	75	72	57	81

Table 5. Dosimetric comparison between electronic brachytherapy (eBT) and HDR ^{192}Ir (as % of 7 Gy prescribed dose)

Parameter	^{192}Ir, mean ±SD (range)	eBT, mean ±SD (range)	*p*-value
CTV $D_{90\%}$	101.2 ±2.3 (98-105)	100.7 ±2.5 (97-104)	0.487
CTV $V_{150\%}$	31.4 ±3.9 (24-38)	36.1 ±4.3 (29-44)	0.063
CTV $V_{200\%}$	10.8 ±2.5 (7-15)	14.2 ±3.0 (9-19)	0.071
Bladder D_{2cc}	69.8 ±4.7 (61-78)	65.5 ±4.2 (58-73)	0.112
Bladder D_{1cc}	72.0 ±3.5 (64-80)	71.0 ±3.8 (63-79)	0.675
Bladder $D_{0.1cc}$	74.5 ±3.9 (67-82)	78.2 ±4.5 (70-87)	0.205
Rectum D_{2cc}	67.9 ±4.3 (60-76)	64.8 ±4.1 (57-72)	0.245
Rectum D_{1cc}	70.1 ±3.8 (63-77)	70.5 ±4.0 (63-78)	0.782
Rectum $D_{0.1cc}$	72.8 ±4.0 (65-81)	74.7 ±4.2 (67-83)	0.301
Sigmoid D_{2cc}	62.9 ±4.2 (55-70)	59.8 ±4.1 (52-67)	0.158
Sigmoid D_{1cc}	68.2 ±3.9 (60-75)	68.4 ±4.0 (60-76)	0.894
Sigmoid $D_{0.1cc}$	71.6 ±4.1 (64-79)	72.4 ±4.0 (65-80)	0.725

cancer, particularly in centers without access to ^{192}Ir HDR brachytherapy. While ^{192}Ir remains the gold standard due to its flexibility in treating multiple anatomical sites, eBT presents unique advantages, including reduced shielding requirements, mobility, and lower maintenance costs associated with source handling. These attributes align with findings from previous studies, which highlight the practicality of eBT in centers with limited infrastructure or in low-resource settings [12, 20]. Additionally, eBT can represent a valuable complementary option for centers performing brachytherapy treatments with high volumes. However, it should be noted that eBT cannot be utilized for interstitial brachytherapy procedures due to larger diameter of its source.

Importantly, this study does not suggest replacing ^{192}Ir with eBT, but rather identifies its complementary role. By selectively allocating eBT for endometrial cancer as well as other indications, including non-melanoma skin cancer and intraoperative radiotherapy for breast cancer, ^{192}Ir can be reserved for more complex treatments, such as cervical cancer, requiring interstitial components [22, 23]. This approach optimizes resource allocation and ensures that the broad spectrum of ^{192}Ir applications is maintained while expanding access to brachytherapy for less technically demanding cases.

We acknowledge that the construction cost of a dedicated brachytherapy bunker for ^{192}Ir treatments could be allocated on a per-patient basis. For instance, assuming a construction cost ranging between €500,000 and €1,000,000 and amortizing this investment over 30 years with an annual patient volume of 200, the resulting per-patient cost would be estimated between approximately €83 and €166, respectively. However, this cost was not directly incorporated into our economic analysis for several reasons. First, there is substantial variability in bunker construction costs due to differences in local market conditions and contractor pricing, which makes a universal estimate challenging. Second, while eBT does not include bunker-related expenses, ^{192}Ir brachytherapy is often employed across a broader spectrum of clinical applications beyond endometrial cancer. This wider utilization allows facilities to distribute the bunker cost over a larger patient population, further diluting the per-patient expense. Given that our study specifically focused on endometrial treatments, we opted not to directly add this variable cost to each patient's result, thereby ensuring that our economic evaluation remains both focused and reflective of real-world clinical practice.

Considering the number of sessions performed annually (740 on average) at the analyzed ^{192}Ir center, each additional endometrial patient treated would reduce the cost per-patient by approximately 0.5% of the equipment cost (Table 3), provided there is sufficient time to accommodate them, and considering other patient locations. Conversely, with eBT, each additional endometrial treatment would increase the cost by approximately 0.08%, which could lead to a convergence of both modalities in terms of cost per patient when treating a sufficiently high number of cases. However, prioritizing endometrial treatments with ^{192}Ir would influence the availability of the system for other localizations, typically more demanding in terms of professional time, thus reducing the overall treatment capacity and flexibility of the HDR unit. Additionally, at the ^{192}Ir center, the maximum number of treatments is already being performed with the available staff, making it unfeasible to increase the number of patients. Therefore, in this scenario, extrapolating costs as a function of the number of patients would be difficult. Although, the relative cost per patient decreases with more patients in the ^{192}Ir scenario, but increases in the eBT scenario, due to the different allocation of source-related costs per irradiation minute. This underscores the strategic advantage of complementing the ^{192}Ir system with eBT in such situations, preserving versatility while optimizing resource allocation.

Dosimetric outcomes in this study align with previous research indicating that eBT achieves comparable CTV coverage to ^{192}Ir while reducing doses to OARs, such as the bladder and rectum [8, 11, 23]. This is particularly relevant in demonstrating its safety profile, as observed in studies where acute and long-term toxicities were minimal, even in higher dose regions, such as the

vaginal mucosa [23]. Clinicians must weigh these factors when selecting the appropriate modality to optimize patient outcomes.

Economic analyses also support the feasibility of eBT, particularly when considering savings associated with eliminating radioactive source handling (eBT source replacements are less costly and logistically simpler compared with radioactive source replacements) and minimizing logistical burdens. Previous studies demonstrated how reducing fractions in vaginal cuff brachytherapy significantly decreased costs without compromising clinical outcomes [8]. Similar savings are evident when eBT is incorporated for exclusive endometrial treatments, leveraging its mobility and reduced infrastructure demands [24].

Conversely, HDR ^{192}Ir brachytherapy systems have lower upfront costs, but incur ongoing expenses related to source replacement and rigorous safety protocols. A longer half-life of alternative isotopes, such as cobalt-60 (^{60}Co) was proposed as a cost-effective option, reducing the frequency of source replacements. However, ^{60}Co presents its own set of dosimetric [25] and logistical considerations [26]. Dosimetrically, ^{60}Co and ^{192}Ir sources are comparable in clinical applications, with studies indicating negligible differences in treatment outcomes [27]. However, ^{60}Co's higher energy emissions necessitate additional shielding considerations in facility design and may require specific regulatory approvals, potentially impacting initial setup costs and operational logistics. In terms of costs, while ^{60}Co sources may have a higher upfront acquisition costs, the extended replacement interval can lead to lower cumulative expenses over time. This cost dynamic is particularly beneficial for centers with limited resources, or those aiming to minimize frequent source procurement and associated logistical challenges.

This study offers a comprehensive evaluation of both the dosimetric and economic aspects of eBT and HDR ^{192}Ir brachytherapy, making it the only investigation to directly compare economic aspects of these modalities in post-operative treatment of endometrial cancer. The inclusion of 185 patients from two centers ensures a robust dataset, improving the reliability of the findings. Furthermore, the detailed dosimetric data, with parameters, such as D_{2cc}, D_{1cc}, and $D_{0.1cc}$ for OARs, offer valuable insights into the clinical implications of each modality. The economic analysis, which calculates costs per session while considering both source replacement and maintenance expenses, provides an additional layer of practicality to the study.

Despite its strengths, the current research has several limitations, which should be acknowledged. First, the analysis excludes certain indirect costs, such as those related to personnel training, infrastructure upgrades, and long-term maintenance beyond the evaluation period. Second, the study does not include clinical follow-up data on toxicities or oncologic outcomes, which limits the ability to correlate dosimetric and economic findings with patient quality of life or disease control. Finally, the generalizability of these results may be constrained by the specific settings of the two centers included, as institutional practices and cost structures can vary significantly. Additionally, the findings may not be directly applicable to other countries or centers with different workloads or operational conditions, where the volume of treatments and available resources could influence the cost-efficiency observed in this study.

These limitations highlight the need for caution when applying the findings to other clinical settings, emphasizing the importance of individualized decision-making based on local resources and patient populations.

It should be noted that HDR brachytherapy sources, such as ^{192}Ir, deplete continuously due to radioactive decay regardless of patient throughput. Consequently, healthcare centers already having HDR brachytherapy afterloaders can potentially improve resource efficiency and economic sustainability by increasing the utilization of these units for additional clinical indications, such as interstitial prostate brachytherapy, rather than automatically defaulting EBRT. This strategic approach to brachytherapy resource management could lead to better optimization of source usage, thus enhancing cost-efficiency and potentially offsetting the apparent economic advantages identified in eBT compared with HDR brachytherapy.

This consideration might significantly influence the cost-benefit conclusions derived from the present analysis. Specifically, if the HDR afterloader equipment is utilized for multiple anatomical sites or diverse clinical indications, the cost per patient attributed to source replacement and maintenance decreases substantially due to broader resource allocation. Therefore, the calculated economic differences favoring eBT in scenarios strictly limited to endometrial cancer treatments could be narrowed or even reversed, if broader clinical applications of HDR brachytherapy are considered.

Additionally, the relatively low cost of treating endometrial cancer patients could support the complementary usage of eBT in centers equipped with both technologies. This would allow healthcare providers to efficiently allocate resources, utilizing HDR for more complex or resource-intensive procedures while reserving eBT for less technically demanding treatments, thereby optimizing overall cost-effectiveness and operational flexibility.

Future research should focus on integrating clinical outcomes with dosimetric and economic analyses to provide a more comprehensive understanding of long-term implications of eBT and ^{192}Ir HDR brachytherapy. Studies exploring the impact of eBT on acute and late toxicities, particularly in high-dose regions, such as the vaginal mucosa, are warranted to further validate its safety profile. Moreover, comparative studies involving newer technologies and isotopes, such as ^{60}Co or advanced eBT systems, could shed light on potential improvements in cost-effectiveness and clinical performance.

Technological advancements may also influence the cost structure and clinical adoption of these modalities. Innovations in source design, applicator systems, and treatment planning algorithms can enhance the efficiency and precision of eBT and ^{192}Ir HDR, potentially narrowing the economic gap between the two techniques. Moreover, expanding the indications for eBT beyond en-

dometrial cancer to include other gynecologic or non-gynecologic malignancies might improve its cost-effectiveness through higher utilization rates.

Conclusions

This study demonstrates that both eBT and HDR ^{192}Ir brachytherapy achieve comparable dosimetric outcomes in the exclusive treatment of the vaginal cuff following surgery for endometrial cancer. While the allocation of costs to endometrial cylinder treatments remains complex due to the shared use of HDR equipment for a variety of indications, eBT presents distinct advantages by reducing the relative recurrent costs (based on Spanish pricing) associated with radioactive source management and by lessening infrastructure demands.

With combining economic and dosimetric evaluations, this work offers a comprehensive framework of technology selection, advocating for a complementary model, in which eBT is prioritized for less complex cases and HDR ^{192}Ir is reserved for broader or more demanding clinical applications, ultimately optimizing resource use and patient outcomes.

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