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ORIGINAL ARTICLE

Centralization of MR image-guided adaptive brachytherapy for cervical cancer in Austria: feasibility and outcomes

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Abstract

Purpose Magnetic resonance image-guided adaptive brachytherapy (MR-IGABT) is the standard of care for definitive radiochemotherapy in locally advanced cervical cancer, but radiotherapy departments with sufficient case volume and unrestricted access to MRI capacity remain limited. This study evaluated the feasibility and outcomes of a nationwide Austrian model combining decentralized external-beam radiotherapy (EBRT) with centralized MR-IGABT.

Materials and methods This retrospective cohort study included patients with FIGO IB–IVA cervical cancer treated between 2018 and 2022 who received EBRT ± concomitant chemotherapy at external Austrian institutions and were subsequently referred to the Medical University of Vienna for brachytherapy. All patients received four fractions of MR-IGABT with MRI-based target delineation according to GEC-ESTRO recommendations. Primary endpoints were local control (LC) and overall survival (OS). Secondary endpoints included pelvic lymph node control (PLNC), recurrence-free survival (RFS), and grade ≥ 3 morbidity requiring medical intervention.

Results Eighty-nine patients from nine institutions were analyzed. Median age was 52 years; 54% had T2b disease and 60% nodal involvement, including 17% paraaortic nodes. Median overall treatment time was 50 days, with a median 6.5-day interval between EBRT and brachytherapy. Combined intracavitary/interstitial brachytherapy was used in 87%, with a median of six needles. The median CTV_{HR} D90 was 91 Gy EQD2. After a median follow-up of 36 months, the estimated 3-year OS was 74%, LC 95%, PLNC 95%, and RFS 65%. Recurrences were predominantly distant. Grade ≥ 3 morbidity occurred in 26.1%.

Conclusion Centralized MR-IGABT within a nationwide referral network is feasible and enables guideline-conform, high-quality cervical cancer treatment in a real-world setting.

Keywords Radiotherapy · Chemotherapy · Real world data · EMBRACE · Interstitial

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Introduction

Brachytherapy (BT) is an essential component of the treatment of locally advanced cervical cancer. Major conceptual and technical improvements [1, 2] over the past 20 years have led to the development of MR image-guided adaptive brachytherapy (MR-IGABT). MR-IGABT enables adaptation of the brachytherapy dose according to the individual tumor extent, including the response to external radiochemotherapy preceding BT, and to the patient-specific spatial location of the surrounding organs. It has demonstrated superior local control and overall survival and lower toxicity in comparison to X-ray-based brachytherapy using applicator-related dose points. Based on the excellent results of the EMBRACE study [3], the ESGO-ESTRO-ESP guidelines [4] defined IGABT (preferably with MRI as the imaging modality) as the standard of care in definitive radiochemotherapy for locally advanced cervical cancer. However, despite this success story, implementation of MR-IGABT is limited outside of radiotherapy departments with sufficient case volume and unrestricted access to MRI capacity. Major obstacles to implementing MR-IGABT are the required infrastructure [5, 6] and expertise on the one hand, and the relatively low patient numbers in centers without the respective specialization on the other. Therefore, centralization of gynecologic brachytherapy appears to be key to pool resources and offer patients optimal-quality care. Therefore, the Department of Radiation Oncology of the Medical University of Vienna (MUV), as a major pioneer in the field of MR-IGABT and leading center of the EMBRACE studies, initiated collaboration regarding MR-IGABT services with radiation oncology centers across Austria in 2018. Herein, we present the feasibility and clinical outcomes of the resulting MR-IGABT centralization in locally advanced cervical cancer in Austria.

Materials and methods

This retrospective study was conducted at the Department of Radiation Oncology of the MUV. Ethical approval was obtained from the institutional ethics committee (EK Nr. 1489/2023). The study analyzed oncologic outcomes in patients with cervical cancer who had received external-beam radiotherapy (EBRT) ± concomitant chemotherapy at external institutions in Austria and were subsequently referred to the MUV for brachytherapy between 2018 and 2022.

Eligible patients had histologically confirmed locally advanced cervical cancer of FIGO 2009 stage IB–IVa and were treated with definitive radiochemotherapy and MR-IGABT. Inclusion required completion of EBRT at an external clinic and delivery of brachytherapy at MUV within the study period. Patients treated entirely at MUV or with synchronous malignancies or distant metastases at diagnosis were excluded.

Patient referral procedure

External centers were asked to send all relevant available patient information (histology report, report of gynecological examination, staging including [PET-]CT of abdomen and chest, pelvic MRI) before the start of EBRT to MUV. The indication for IGABT was checked, and appointments for BT were scheduled according to the expected commencement of EBRT with/without chemotherapy. If geographically feasible, patients were also asked to come to MUV for a gynecologic examination prior to the start or at the beginning of EBRT. Patients were admitted to the Department of Radiation Oncology of the MUV's ward 2 days prior to the first scheduled MR-IGABT to perform preanesthetic clearance (blood work, X-ray of the chest, ECG) and bowel preparation, to repeat MRI for treatment planning, and to obtain written informed consent.

External-beam radiotherapy

External-beam radiotherapy was performed at the respective referring centers, which had agreed to follow the EMBRACE II protocol [7] for EBRT and chemotherapy. In short, treatment planning was based on MRI-defined primary tumor volumes including internal target volumes (ITV-T) to account for organ motion and risk-adapted elective clinical nodal target volumes (CTV-E) of the pelvis ± the paraaortic region ± groin, with simultaneously integrated boosts to affected lymph nodes. Planning target volumes (PTV) were generated using standardized margins of 5 mm, and IMRT/VMAT with daily IGRT was mandatory. Treatment was delivered in 25 fractions of 1.8 Gy to 45 Gy to the elective volumes and 55 or 57.5 Gy to nodal boosts. Concomitant chemotherapy consisted of weekly cisplatin with a dose of 40 mg/m^2 body surface area. The EBRT treatment plans were sent to MUV for evaluation and dose summation. This evaluation included the prescribed and delivered total dose, any additional boost doses, and target coverage. The contours were not systematically reviewed in detail. However, structured feedback was provided to the referring centers when major deviations from the EMBRACE II protocol were identified.

Brachytherapy

All patients underwent four fractions of MR-IGABT at MUV using HDR BT with an Ir-192 source. Target volumes followed GEC-ESTRO definitions: residual gross tumor volume (GTV_{res}), high-risk clinical target volume (CTV_{HR}), intermediate-risk CTV (CTV_{IR}) [2]. Dose pre-

scription aimed for a total of ≥ 90 Gy EQD2 (α/β = 10 Gy) to 90% of CTV_{HR} (D_{90}). Organ at risk (OAR; α/β = 3 Gy) soft constraints for total dose according to the EMBRACE II protocol [7] were as follows: bladder < 80 Gy EQD2, rectum < 65 Gy EQD2, and sigmoid and bowel < 70 Gy EQD2. Applicator type (intracavitary vs. interstitial hybrid) and number of needles were documented.

Follow-up

All patients were offered follow-up (FU) at MUV. Standard FU at MUV includes visits after 2 and 6 weeks for clinical examination. Visits thereafter are scheduled at 3-month intervals for the first 2 years, at 6-month intervals for the third to fifth years, and at yearly intervals thereafter. Gynecologic examination, morbidity assessment, and blood tumor markers (SCC and CEA) are mandatory at every visit. Pelvic MRI and thoracic + abdominal CT are performed alternately, but at least every 12 months during the first 5 years and also yearly thereafter. Due to long traveling distances from different regions within Austria, FU at local referring or treating institutions was also possible. However, all patients were requested to come for at least the 3-month FU to assess complete remission and then once a year or in the instance of suspicious findings. Referring centers were asked to complete FU data of patients who were unable to attend FU visits at MUV personally. Patients who did not attend any FU at MUV or at their referring center were called by phone to ask about possible side effects or recurrences.

Data management

Patient data were obtained from the hospital information system. For parameters not available internally, standardized data-request forms were sent to the referring centers. Survival status was verified via Statistics Austria (last update April 2026). Telephone follow-up was performed in February 2024 for patients alive at last contact. All data were pseudonymized before analysis.

Analysis

The primary endpoints were local control (LC), defined as the time from the start of EBRT to local recurrence or last follow-up, and overall survival (OS), defined as the time from the start of EBRT to death or last follow-up. Secondary (exploratory) endpoints included pelvic lymph node control (PLNC); recurrence-free survival (RFS); and morbidity requiring medical intervention, equaling toxicity > grade 2 according to the Common Terminology Criteria of Adverse Events (CTCAE; version 5). Logistical and clinical feasibility were assessed using the overall treatment time and CTV_{HR} D90, respectively.

Descriptive statistics were used to summarize patient, tumor, and treatment characteristics. Categorical variables were reported as absolute and relative frequencies, continuous variables as mean ± standard deviation, median, and interquartile range (IQR). Survival outcomes were estimated using the Kaplan–Meier method. Statistical analyses were performed with IBM SPSS Statistics 29.0.2.0 (IBM Corp., Armonk, NK, USA).

Results

From 2018 to 2022, a total of 94 patients from 9 national institutions (Linz, Vöcklabruck, Hietzing, Krems, Wiener

Table 1 Patient, treatment, and outcome data. Data are presented as *n*/*N* (%) unless otherwise stated. Percentages were rounded to whole numbers; denominators reflect available cases where data were missing.

Characteristic	Value *n* (%)
Patient and tumor characteristics	
Cohort size	89
Age at treatment initiation, years	Median 52 (range 28–87)
Histology	Squamous cell carcinoma 73 (85); adenocarcinoma 11 (13); adenosquamous carcinoma 2 (2)
Local tumor stage	T1b2 6 (7); T2a 7 (8); T2b 48 (54); T3a 3 (3); T3b 18 (20); T4 6 (7)
Lymph node involvement	53 (60)
Paraaortic lymph nodes	15 (17)
Treatment characteristics	
Concomitant chemotherapy	84 (94)
Combined intracavitary/interstitial brachytherapy	77 (87)
Number of needles	Median 6 (range 2–15)
Interval from EBRT to brachytherapy, days	Median 6.5 (IQR = 6)
CTV_{HR}, cm^3	Median 33 (IQR = 25)
Overall treatment time, days	Median 50 (IQR = 7)
Outcome	
Median follow-up, months	50 (OS), 36 (all other)
Grade ≥ 3 morbidity requiring medical intervention	23 (26)
Any recurrence	24 (27)
Recurrence pattern	Residual disease 1 (1); local 3 (3); pelvic nodal 4 (4); distant 16 (18)

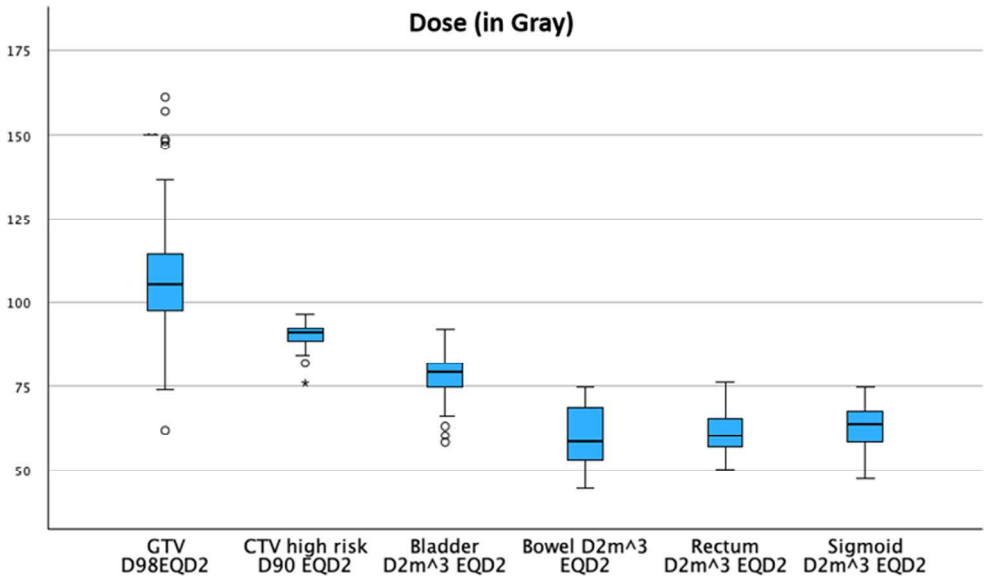


Fig. 1 Median dose and interquartile range for targets and organs at risk

Neustadt, Klagenfurt, Feldkirch, Graz, Donaustadt) and abroad [$n = 3$]) were referred for brachytherapy; 89 (95%) had primary cervical cancer according to the inclusion criteria and were available for analysis. Patient characteristics can be found in Table 1. Median age at treatment initiation was 52 years (range 28–87). The majority of patients (54%) presented with stage T2b. Lymph node involvement was detected in 60%, with 17% having positive paraaortic nodes. Most tumors were squamous cell carcinomas (85%).

Feasibility of treatment

The median overall treatment time was 50 days (IQR = 7 [45–52]), and the median interval between EBRT and brachytherapy was 6.5 days (IQR = 6 [5–11]). The mean CTV_{HR} was 40 cm^3 (median 33 cm^3; range 8.4–141 cm^3). The median elective EBRT dose was 45 Gy (range 45–50.4 Gy). The majority of patients (87%) underwent combined intracavitary/interstitial brachytherapy; the median number of needles was 6 (range 2–16). Concomitant chemotherapy had been administered in 94% of the cases. The median EQD2 D90 for CTV_{HR} was 91 Gy (IQR = 6

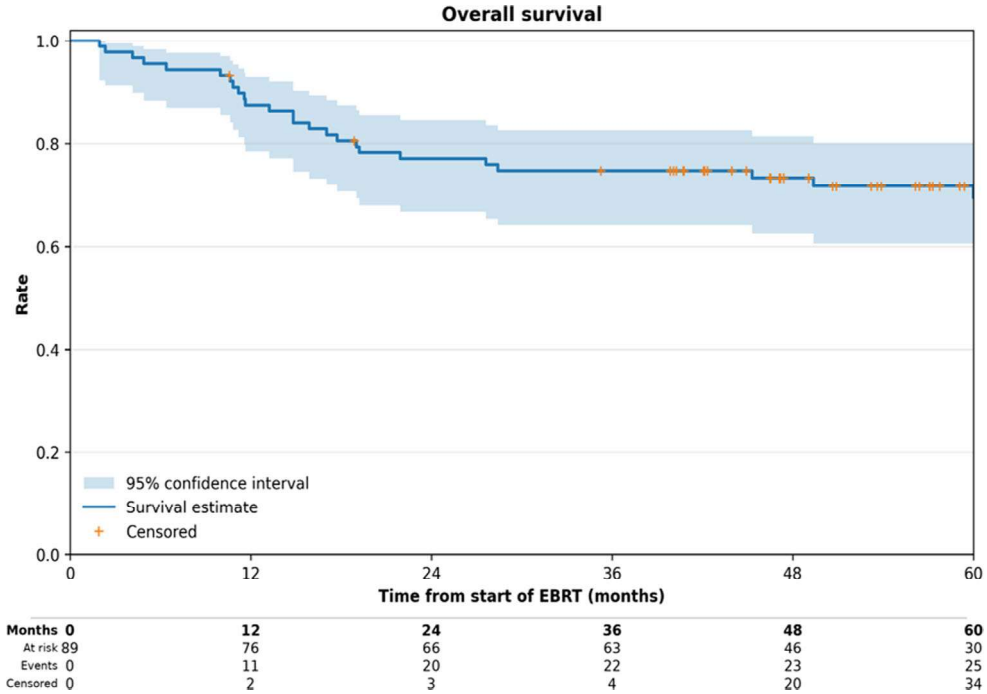


Fig. 2 Kaplan–Meier estimate of overall survival

[87–93]), and the median GTV D98 was 107 Gy (IQR = 17 [98–115]) EQD2. Median D_{2cm3} doses to organs at risk were as follows: bladder 77 Gy (IQR = 8 [73–81]), rectum 62 Gy (IQR = 10 [57–67]), sigmoid 62 Gy (IQR = 11 [57–68]), and bowel 59 Gy EQD2 (IQR = 16 [52–68]; Fig. 1).

Outcome

With a median follow-up of 50 months for OS and a median follow-up of 36 months for the other endpoints, the estimated 3- and 5-year OS were 74% (95% CI: 64–83%) and 69% (95% CI: 58–78%; Fig. 2), and 3-year estimations for LC were 95% (95% CI: 89–99%; Fig. 3), for PLNC 95% (95% CI: 89–99%), and for RFS 65% (95% CI: 54–79%; Fig. 4). Recurrences predominantly occurred

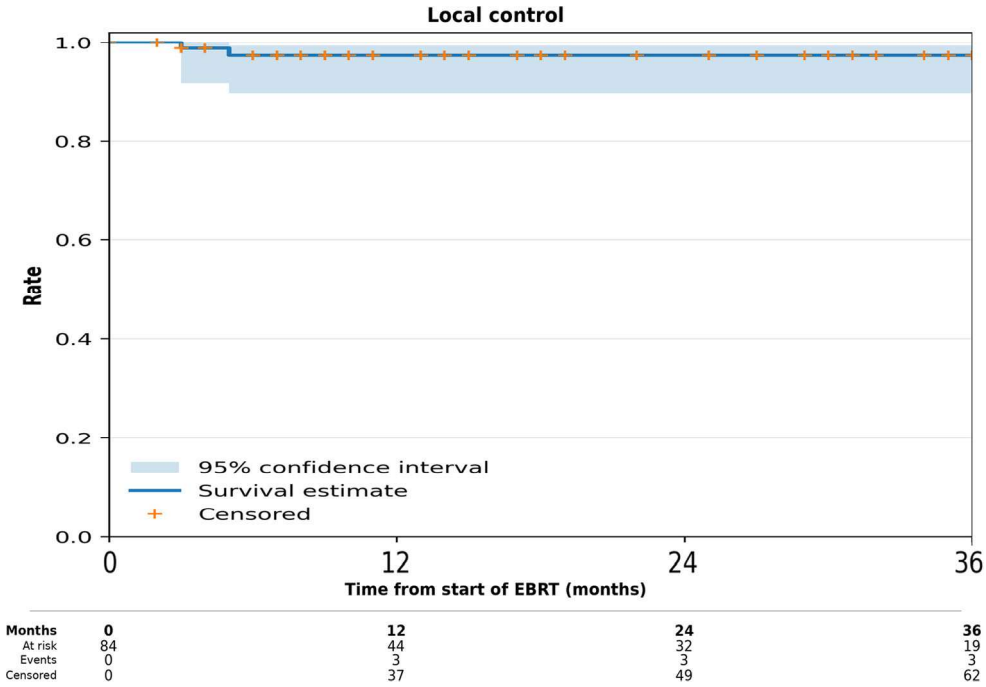


Fig. 3 Kaplan–Meier estimate of local control

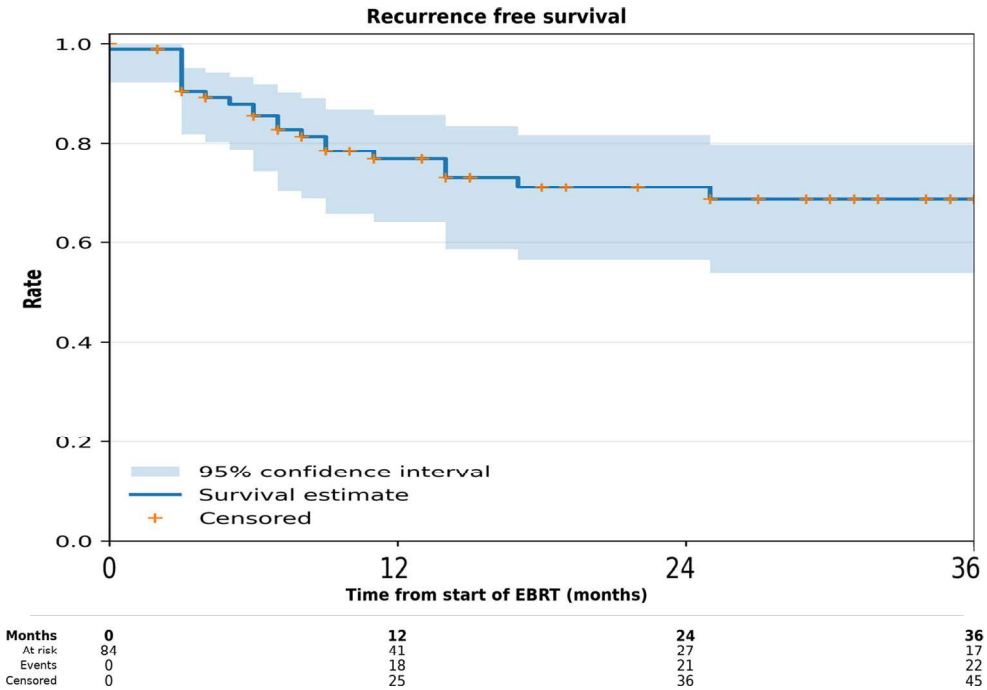


Fig. 4 Kaplan–Meier estimate of recurrence-free survival

as distant metastases (Table 1). Only one patient had persistent local disease.

Twenty-three patients (26%) experienced grade ≥ 3 morbidities requiring medical intervention. The most frequent events were hydronephrosis (7%), anemia requiring transfusion (6%), bladder toxicity (6%), vaginal stenosis (5%), and vesicovaginal fistula (3%).

Discussion

This analysis with data from the majority of Austrian radiotherapy departments suggests that centralization of MR-IGABT for locally advanced cervical cancer is feasible and results in oncologic outcomes comparable to those achieved in prospective international trials [3]. With a 3-year local control rate of 95% and overall survival of 74%, the present data align closely with the landmark EMBRACE I study, which reported 5-year local control rates of 92% and 5-year overall survival of 74% in the entire cohort [3]. Importantly, the outcomes presented here were achieved in a real-world referral setting, in which EBRT was delivered across nine institutions and brachytherapy centralized at a single tertiary center. The high proportion of combined intracavitary/interstitial applications (87%) was slightly higher than in EMBRACE II (74%) [8], which reflects the advanced stage distribution (30% T3/T4 tumors) and underscores the need for specialist expertise concentrated within centralized centers.

A comparable referral-based model was reported by Bentahila et al., in which patients received EBRT in French overseas territories and were referred to Gustave Roussy for IGABT [9]. The 2-year local control rate was 94.6%, supporting the feasibility of centralized brachytherapy, although the median overall treatment time of 60.5 days highlighted the importance of early referral and structured coordination.

Prolongation of the overall treatment time beyond 7–8 weeks has consistently been associated with inferior local control [10] and overall survival [11] in cervical cancer. In the present study, the median interval between EBRT and brachytherapy was 6.5 days, and the median overall treatment time was 50 days (IQR = 7 [45–52]), remaining within the recommended threshold of 56 days [12], a benchmark emphasized in EMBRACE analyses and formalized in the EMBRACE II protocol [7]. These findings support the feasibility of structured coordination between referring institutions and the brachytherapy center, which was associated with maintenance of recommended treatment timelines.

The EMBRACE I cohort, comprising 1341 patients treated with IGABT between 2008 and 2015, demonstrated a 5-year local control rate of 92%, pelvic control of 87%, cancer-specific survival of 84%, and overall survival of 74% [3]. In patients with FIGO stage IIB–IIIB disease, 5-year overall survival ranged between 65% and 80%, depending on nodal status. The present 3- and 5-year overall survival of 74% and 69% therefore completely aligns within the expected survival range of this stage distribution, particularly considering that 60% of patients in our cohort had nodal involvement and 17% paraaortic disease.

Direct comparison to EMBRACE I in terms of toxicity (>G2: 14.6%) must be interpreted cautiously, as EMBRACE I toxicity reporting focused primarily on late morbidity, whereas the current cohort included both acute and late events. Moreover, the advanced disease burden and real-world follow-up structure may partially explain the observed differences. Nevertheless, the toxicity profile remains within an acceptable range in view of the achieved tumor control.

Consistent with EMBRACE I, where distant metastases represented the predominant mode of failure despite excellent local control [3], the present cohort had an estimated 3-year recurrence-free survival of 65%, with recurrences mainly occurring distantly. This observation reinforces the concept that modern MR-IGABT has largely optimized local tumor control, and further outcome improvements will likely depend on advances in systemic therapy rather than additional local dose escalation. Recent guideline updates from ESGO-ESTRO-ESP [4] emphasize the integration of optimized radiochemotherapy as the backbone of treatment.

EMBRACE II further refined dosimetric aims, recommending CTV_{HR} D90 ≥ 90 Gy EQD2 while maintaining strict organ at risk constraints [7]. In the present cohort, the median CTV_{HR} D90 was 90.5 Gy EQD2, and median D2cm3 doses were 77 Gy for bladder, 62 Gy for rectum, 62 Gy for sigmoid, and 59 Gy for bowel. These values demonstrate adherence to EMBRACE II overall dose objectives despite decentralized EBRT delivery, underscoring the robustness of centralized brachytherapy planning and dose summation. However, the overall clinical outcome in our cohort was less favorable than that reported for EMBRACE II [13]. This suggests that while dosimetric robustness was preserved, outcome differences are likely influenced by additional factors such as patient and disease characteristics, treatment duration, and the challenges of coordinating multimodality treatment across institutions.

The present findings provide empirical support for centralized MR-IGABT networks in countries with distributed patient populations and limited case numbers per institution and may also serve as a benchmark for larger countries with a well-developed radiotherapy infrastructure. A key prerequisite for achieving favorable outcomes in a centralized gynecological brachytherapy setting is close and well-structured collaboration between the referring and treating institutions. Ideally, patients should be discussed before the

start of treatment, with coordinated treatment planning and presentation in a multidisciplinary tumor board. To further support patient-centered care and continuity, some centers offered the possibility for patients to be accompanied by their treating physicians from the referring hospital during brachytherapy at the centralized center. MR-IGABT requires MRI availability at each fraction, radiation oncologist expertise in GEC-ESTRO contouring, interdisciplinary experience with interstitial techniques for implantation and dose plan optimization, and competence in cumulative dose calculation. In addition, dedicated medical physicists with expertise in MR-based applicator reconstruction, treatment planning, and image-guided quality assurance are essential. A robust and meticulously quality-assured hypofractionation workflow is also required, including stable implant geometry, repeated MR verification, organ filling protocols, and tightly coordinated treatment processes. Moreover, centers must have access to a broad range of complex applicators for diverse clinical scenarios, as well as the ability to adapt the applicator choice and technique creatively in nonstandard situations. Mastery and availability of transrectal ultrasound during applicator insertion further support accurate placement, while optimized MR sequences and radiotherapy-driven MR quality assurance are crucial, particularly for MR-only brachytherapy workflows. Finally, a complex infrastructure of operating room availability, dedicated nursing, specialized radiotherapy technicians, dedicated anesthesiologists, and secure standardized data exchange between centers is necessary. In low-volume centers, maintaining this level of expertise and infrastructure may be challenging. Centralizing cases within specialized centers enables accumulation of procedural experience, protocol adherence, and systematic quality assurance. In addition, centralized treatment may have the potential to improve resource utilization and may represent a cost-efficient healthcare model. However, centralization may also have unintended consequences, including erosion of brachytherapy expertise in nonspecialized centers and reduced exposure to the technique for future generations. These potential drawbacks highlight the need for network-based collaboration, structured training pathways, and shared educational initiatives.

This study has several notable strengths. First, it represents a nationwide real-world cohort including patients referred from nine Austrian institutions, thereby reflecting daily clinical practice beyond a single-center experience. Second, follow-up was mature, with a median duration of 36 months, thus allowing meaningful assessment of intermediate-term oncologic outcomes. Third, adherence to EMBRACE II dose objectives and systematic central dose summation ensured high-quality dosimetric consistency across cases. Fourth, the high proportion of hybrid intracavitary/interstitial applications supports the notion that technically demanding procedures were feasible within a centralized structure. Finally, the structured collaboration between decentralized EBRT centers and a single brachytherapy center provides a practical and reproducible blueprint that may serve as a model for other healthcare systems.

The retrospective nature of this study limits causal inference, and referral and selection bias cannot be excluded. Only patients who were successfully referred to and treated at the central brachytherapy center were included, while information on potentially eligible patients who were not referred, declined referral, or were treated locally was unavailable. In addition, some baseline characteristics, including ECOG performance status, tumor size, and comorbidities, were not consistently available. Although EBRT was recommended according to EMBRACE II standards, heterogeneity between referring institutions cannot be fully excluded. Toxicity was assessed retrospectively, partly through referring centers or telephone follow-up, precluding a reliable distinction between acute and late events. Some toxicities may also have reflected pre-existing or tumor-related conditions. Follow-up duration remained shorter than the 5-year EMBRACE benchmark. Nonetheless, the consistency of survival and local control outcomes with prospective international data strengthens the validity of the findings.

Conclusion

The Austrian model suggests that centralized brachytherapy alongside decentralized EBRT is feasible and can achieve high-quality, guideline-conform treatment and oncologic outcomes consistent with international benchmarks in a nationwide referral setting. This approach has the potential to improve resource utilization and represents a feasible model for national MR-IGABT networks.

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Author Contribution All authors contributed to study conception and design. Material preparation, data collection, and data analysis were performed by Hazem Ramadan, Maximilian Schmid, and Johannes Knoth. The first draft of the manuscript was written by Johannes Knoth, and all authors commented on previous versions of the manuscript. All authors have read and approved the final manuscript.

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Data availability All data supporting the findings of this work are included in the article.

Declarations

Ethical standards This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the Medical University of Vienna (EK Nr. 1489/2023).

Conflict of interest J. Knoth, H. Ramadan, E.M. Weis, G. Kurzweil, B. Celedin, O. Komina, J. Salinger, J. Böswarth, S. Skorbier, M. Buchegger, S. Kartal, S. Flatz, J. Frey, O. Gomez, M. Kopp, M. Metz, A. de Vries, T. Brunner, J. Widder, A. Reim, N. Eder-Nesvacil, C. Kirisits, W. Raunik, P. Georg, H. Geinitz, A. Sturdza, and M.P. Schmid declare that they have no competing interests. The Department of Radiation Oncology at the Medical University of Vienna has institutional research contracts with RaySearch Laboratories (Sweden), ELEKTA Ltd. (Sweden), Philips Austria GmbH (Austria), and Brainlab SE (Germany), which are not related to this study.

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References

1. Pötter R, Haie-Meder C, Van Limbergen E, Barillot I, De Brabandere M, Dimopoulos J et al (2006) Recommendations from gynaecological (GYN) GEC ESTRO working group (II): concepts and terms in 3D image-based treatment planning in cervix cancer brachytherapy-3D dose volume parameters and aspects of 3D image-based anatomy, radiation physics, radiobiology. Clin Transl Radiat Oncol 78(1):67–77. https://doi.org/10.1016/j.radonc.2005.11.014 (PubMed PMID: 16403584)
2. Haie-Meder C, Pötter R, Van Limbergen E, Briot E, De Brabandere M, Dimopoulos J et al (2005) Recommendations from Gynaecological (GYN) GEC-ESTRO Working Group (I): concepts and terms in 3D image based 3D treatment planning in cervix cancer brachytherapy with emphasis on MRI assessment of GTV and CTV. Clin Transl Radiat Oncol 74(3):235–245. https://doi.org/10.1016/j.radonc.2004.12.015 (PubMed PMID: 15763303)
3. Pötter R, Tanderup K, Schmid MP, Jürgenliemk-Schulz I, Haie-Meder C, Fokdal LU et al (2021) MRI-guided adaptive brachytherapy in locally advanced cervical cancer (EMBRACE-I): a multicentre prospective cohort study. Lancet Oncol 22(4):538–547. https://doi.org/10.1016/S1470-2045(20)30753-1 (PubMed PMID: 33794207)
4. Cibula D, Raspollini R, Planchamp F, Centeno C, Chargari C, Felix A et al (2023) ESGO/ESTRO/ESP Guidelines for the management of patients with cervical cancer - Update 2023. Clin Transl Radiat Oncol 184:109682. https://doi.org/10.1016/j.radonc.2023.109682 (PubMed PMID: 37336614)
5. Chargari C, Arbyn M, Leary A, Abu-Rustum NR, Basu P, Bray F et al (2022) Increasing global accessibility to high-level treatments for cervical cancers. Gynecol Oncol 164(1):231–241. https://doi.org/10.1016/j.ygyno.2021.10.073 (PubMed PMID: 34716024; PubMed Central PMCID: PMC9496636)
6. LaVigne AW, Triedman SA, Randall TC, Trimble EL, Viswanathan AN (2017) Cervical cancer in low and middle income countries: Addressing barriers to radiotherapy delivery. Gynecol Oncol Rep 22:16–20. https://doi.org/10.1016/j.gore.2017.08.004 (PubMed PMID: 28948205; PubMed Central PMCID: PMC5602511)
7. Pötter R. EMBRACE II study protocol [Internet]. Available from: https://www.embracestudy.dk/UserUpload/PublicDocuments/EMBRACE%20II%20Protocol.pdf
8. Eder-Nesvacil et al. Change of practice in MR-guided adaptive brachytherapy for cervical cancer by a multiparametric dose prescription protocol: From EMBRACEI to EMBRACEII, ESTRO 2025 - Abstract Book S265–6 [Internet]. [cited 2026 Apr 15]. Available from: https://user-swndwmf.cld.bz/ESTRO-2025-Abstract-Book
9. Bentahila R, Rassy E, Achkar S, Sacino F, Bougas S, Vallard A et al (2022) Providing Patients with Locally Advanced Cervical Cancer Access to Brachytherapy: Experience from a Referral Network for Women Treated in Overseas France. Cancers 14(12):2935. https://doi.org/10.3390/cancers14122935 (PubMed PMID: 35740601; PubMed Central PMCID: PMC9221527)
10. Tanderup K, Fokdal LU, Sturdza A, Haie-Meder C, Mazeron R, van Limbergen E et al (2016) Effect of tumor dose, volume and overall treatment time on local control after radiochemotherapy including MRI guided brachytherapy of locally advanced cervical cancer. Clin Transl Radiat Oncol 120(3):441–446. https://doi.org/10.1016/j.radonc.2016.05.014 (PubMed PMID: 27350396)
11. Lin SM, Ku HY, Chang TC, Liu TW, Hong JH (2017) The prognostic impact of overall treatment time on disease outcome in uterine cervical cancer patients treated primarily with concomitant chemoradiotherapy: a nationwide Taiwanese cohort study. Oncotarget 8(49):85203–85213. https://doi.org/10.18632/oncotarget.19617 (PubMed PMID: 29156713; PubMed Central PMCID: PMC5689603)
12. Viswanathan AN, Beriwal S, De Los Santos J, Demanes DJ, Gaffney D, Hansen J et al (2012) The American Brachytherapy Society Treatment Recommendations for Locally Advanced Carcinoma of the Cervix Part II: High Dose-Rate Brachytherapy. Brachytherapy 11(1):47–52. https://doi.org/10.1016/j.brachy.2011.07.002 (PubMed PMID: 22265437; PubMed Central PMCID: PMC3489267)
13. Pötter R (2025) EMBRACE II - a multicenter prospective interventional cohort study on IGRT-IMRT+cisplatin+MR-IGABT in locally advanced cervix cancer: overall results ESTRO 2025 - Abstract Book S837–40. https://user-swndwmf.cld.bz/ESTRO-2025-Abstract-Book. Accessed 15 Apr 2026 (Internet)

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