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Metastasis-directed radiotherapy for oligometastatic cervical carcinoma: Identifying potential beneficiaries

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ABSTRACT

Background: The role of metastasis-directed radiotherapy (MDRT) in oligometastatic cervical carcinoma (OCC) remains unclear. This study evaluated clinical outcomes of MDRT in patients with OCC and identified prognostic factors associated with survival.

Materials and methods: Patients with OCC who received MDRT between 2019 and 2022 were retrospectively reviewed. Eligible patients had ≤ 5 metastatic lesions treated using stereotactic ablative radiotherapy (SABR), defined as radiotherapy delivered in ≤ 5 fractions with a fractional dose of ≥ 5 Gy. Oligometastatic disease was classified according to the ESTRO–EORTC consensus. Radiologic response, patterns of failure, progression-free survival (PFS), overall survival (OS), and treatment-related toxicities were analyzed.

Results: A total of 83 patients with 114 temporally independent MDRT courses delivered using SABR were included. Repeat oligorecurrence was the most common oligometastatic subtype, observed in 35 patients. Lymph nodes were the most frequently treated sites (37 patients, 44.6%). Systemic therapy was administered either before and/or after MDRT in 54 patients (65.1%). With a median follow-up of 20 months, the local control rate was 60.8%, and disease progression predominantly occurred outside the treated fields. The 2-year PFS and OS rates were 14.5% and 62.9%, respectively. In multivariable analysis, oligometastatic disease classification and RT response were independently associated with OS. No grade 3 or higher treatment-related toxicities were observed.

Conclusion: MDRT using SABR achieved favorable outcomes with minimal toxicity in OCC. Oligometastatic disease classification may assist in selecting appropriate patients for MDRT under multidisciplinary approach. Prospective studies are warranted to validate these findings and to define optimal MDRT strategies.

Introduction

Cervical carcinoma can achieve favorable treatment outcomes when surgery, radiotherapy (RT), and chemotherapy are appropriately utilized according to disease stage. Nevertheless, a subset of patients develops limited metastatic spread, commonly referred to as oligometastatic disease, either at initial presentation or following definitive treatment [1]. These oligometastatic states represent a biologically and clinically distinct condition, lying between localized and widely disseminated disease, and raise important questions regarding optimal treatment strategies.

In this background, metastasis-directed radiotherapy (MDRT) has emerged as a feasible local treatment approach aimed at achieving durable control of metastatic lesions with advances in high-precision RT. Stereotactic ablative radiotherapy (SABR), characterized by the delivery of highly conformal, ablative-dose radiation over a limited number of fractions, has been increasingly adopted within MDRT strategies. The efficacy of SABR has been demonstrated in multiple studies [2]. In parallel, the feasibility of SABR as a MDRT modality has been actively investigated [3], including in a prospective phase II trial across various solid tumors that demonstrated improvements in survival outcomes in selected patient populations [4].

Despite growing evidence supporting MDRT in oligometastatic disease, validated data in gynecologic malignancies remain limited [5,6]. Although few retrospective studies have suggested the potential efficacy of SABR in oligometastatic cervical carcinoma (OCC) [7,8], prognostic

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factors specific to these patients after SABR have not been systematically evaluated. Consequently, the role MDRT using SABR remains ill-defined, and appropriate patient selection in this population continues to be challenging. In this study, we evaluated the clinical safety and efficacy of MDRT in patients with OCC and sought to identify clinical subgroups that may derive the greatest benefit from this treatment approach.

Materials and methods

Patient selection

Between January 2019 and December 2022, patients with OCC who received MDRT at Yonsei Cancer Center were retrospectively evaluated. The inclusion criteria were as follows: (i) histologically confirmed cervical carcinoma at the initial diagnosis, (ii) oligometastatic disease involving five or fewer metastatic lesions, and (iii) treatment with SABR, defined as radiotherapy delivered in ≤ 5 fractions with a fractional dose of ≥ 5 Gy. The exclusion criteria were: (i) disseminated stage IVB disease at initial diagnosis, (ii) receipt of suboptimal or incomplete definitive treatment for the primary tumor, (iii) RT delivered with a purely palliative dose, and (iv) inability to deliver sufficient radiation dose due to previous RT.

Patients were classified according to the consensus of the European Society for Radiotherapy and Oncology (ESTRO) and the European Organization for Research and Treatment of Cancer (EORTC) into synchronous oligometastatic disease, oligorecurrence, or oligoprogression [9]. Programmed death-ligand 1 (PD-L1) expression was evaluated using the Combined Positive Score (CPS), with the 22C3 pharmDx assay. CPS was defined as the percentage of PD-L1–positive cells among total number of viable tumor cells. This study was approved by the Institutional Review Board of Yonsei University College of Medicine (IRB No. 4–2024-1604), and the requirement for informed consent was waived due to the retrospective nature of the study.

Treatment and follow-up

Metastatic lesions were identified using contrast-enhanced computed tomography (CT), magnetic resonance imaging (MRI), and/or positron emission tomography (PET)-CT. Candidates for MDRT were selected on a case-by-case basis through multidisciplinary discussions, considering disease extent, prior treatments, and alternative therapeutic options.

Patients were immobilized using customized immobilization devices. For lesions affected by respiratory motion, four-dimensional CT was performed with motion-management techniques including abdominal compression or active breathing control when necessary. CT, MRI, and/or PET-CT images were routinely imported into MIM software (MIM Software Inc., Cleveland, OH, USA) and registered to the planning CT for target delineation. Gross tumor volume (GTV) was defined as the visible tumor. The planning target volume (PTV) was created by adding a 3–5 mm margin to the GTV or to the internal target volume taking respiratory motion into account, without delineation of a clinical target volume. When the boundary between the PTV and adjacent organs at risk (OARs) was indistinct, a 2-mm expansion from the outer edge of the OAR was applied as the limiting boundary of the PTV to ensure organ protection.

Dose fractionation was individualized based on lesion size, location, and proximity to critical OARs. In the present study, all patients were treated with SABR, defined as radiotherapy delivered in ≤ 5 fractions with a fractional dose of ≥ 5 Gy. SABR was delivered every other day, whereas daily fractionation was permitted for bone lesions with sufficient separation from OARs. Systemic therapy was allowed before, after, and during the SABR course. In patients with poor performance status or significant concern for OAR toxicities, systemic therapy and SABR were not administered on the same day. Dose prescriptions allowed a maximum dose of up to 150% of the prescribed dose within the GTV and a minimum of 50% of the prescribed dose at the PTV boundary. Normal tissue dose constraints were primarily based on Timmerman's dose constraints [10]. In addition, specific dose constraints for the bowel, duodenum, and kidneys were applied using EQD_2 ($\alpha/\beta = 3$); bowel $D_{2cc} \leq 45$–55 Gy, duodenum $D_{2cc} \leq 48$–50 Gy, and mean kidney dose ≤ 8–10 Gy. When targets were adjacent to critical OARs, organ preservation was prioritized over full target coverage. All RT plans were generated using volumetric modulated arc therapy with the RayStation treatment planning system (RaySearch Laboratories, Stockholm, Sweden). Daily cone-beam computed tomography was used for image guidance in all patients in every treatment. For lesions subject to respiratory motion, daily four-dimensional CBCT was performed.

The RT response was evaluated where post-MDRT imaging was available according to the Response Evaluation Criteria in Solid Tumors (RECIST), version 1.1 [11]. Treatment-related toxicities were categorized as acute or late toxicities. Acute toxicities were defined as events occurring ≤ 3 months after RT, and late toxicities as events occurring ≥ 3 months after RT. All toxicities were graded according to the Common Terminology Criteria for Adverse Events, version 5.0.

Statistical analysis

Progression-free survival (PFS) was defined as the time from the initiation of MDRT to the date of first disease progression or death, and overall survival (OS) was defined as the time from the initiation of MDRT to death from any cause or the last follow-up, whichever occurred first. PFS and OS were estimated using the Kaplan–Meier method. Multivariable Cox proportional hazards regression models were used to identify factors associated with OS and PFS. For patient-level dose–outcome analyses, the highest prescribed dose, converted to EQD_2 ($\alpha/\beta = 10$), among all MDRT sites was used as the patient-level representative dose metric. For RT response, complete or partial response was defined as a favorable response, whereas others were classified as an unfavorable response. The RT target response for patient-level comparison was categorized based on the worst response among all MDRT target lesions. Local control was evaluated on a per-lesion basis based on post-treatment imaging. Induced oligorecurrence, metachronous oligorecurrence, and repeat oligorecurrence were classified as favorable, whereas all other oligometastatic subtypes were classified as unfavorable, as previous reported [12]. Variables considered clinically relevant and those with p-values < 0.20 in univariate analyses, were included in the multivariable models. Factors with p-values < 0.05 were considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics (version 25.0; IBM Corp., Armonk, NY, USA).

Results

Patient and treatment characteristics

A total of 83 patients with 114 temporally independent MDRT courses encompassing a total of 173 metastatic lesions were included in the final analysis. Patient and treatment characteristics are summarized in Table 1. The median age of the patients was 54 years (range, 25–83). Squamous cell carcinoma (SCC) was the predominant histological type, comprising 55 patients (66.3%), followed by adenocarcinoma in the remaining patients. The PD-L1 CPS was available in 41 patients (49.4%), of whom approximately 80% had a CPS ≥ 1. The most frequently employed primary treatment modality was definitive radiotherapy with concurrent chemotherapy (CCRT), administered in 38 patients (45.8%). According to the ESTRO-EORTC oligometastatic disease classification, the most common subtype was repeat oligorecurrence (31 patients, 37.3%). Among total patients, 21.7% (18 patients) received multiple courses of MDRT for more than two temporally independent oligometastatic disease episodes.

Regarding MDRT target sites, lymph nodes (LNs) were the most frequently treated, involving 37 patients (44.6%), followed by lung,

Table 1
Patient characteristics and treatment profiles.

Profile	N (%) (Total = 83)
Age, year, median (range)	54 (25–83)
Pathology	
SCC	55 (66.3)
Others	28 (33.7)
Primary Treatment	
Definitive CCRT or RT	48 (57.8)
Surgery	21 (25.3)
Neoadjuvant chemotherapy	5 (6.0)
Systemic Chemotherapy	4 (4.8)
Other	5 (6.0)
Point A EQD_2 of primary RT	
<80	8 (9.6)
80–100	47 (56.6)
≥100	28 (33.7)
Classification of oligometastatic disease	
Repeat oligorecurrence	31 (37.3)
Repeat oligoprogression	15 (18.1)
Metachronous oligorecurrence	19 (22.9)
Synchronous oligometastatic disease	11 (13.3)
Induced oligoprogression	4 (4.8)
Induced oligorecurrence	3 (3.6)
Sites	
LN	37 (44.6)
Lung	16 (19.3)
Pelvis including vagina	2 (2.4)
Liver & perihepatic space	7 (8.4)
Bone	6 (7.2)
Others	15 (18.1)
Fractional dose, Gy, median (range)	8.0 (5.0–20.0)
Number of fractions, median (range)	3 (1–5)
Highest prescribed EQD_2, Gy, median (range)	40.0 (29.8–125.0)
Response of RT	
Complete response	9 (10.8)
Partial response	36 (43.4)
Stable disease	11 (13.3)
Progressive disease	25 (30.1)
N/A	2 (2.4)
PD-L1 CPS	
<1	8 (9.6)
≥1	33 (39.8)
N/A	42 (50.6)
Number of RT courses	
1	65 (78.3)
2	15 (18.1)
3	3 (3.6)
Salvage systemic treatment	
ICI only	11 (13.3)
ICI + chemotherapy	4 (4.8)
Chemotherapy only	21 (25.3)
Chemotherapy + targeted agent	17 (20.5)
None	29 (34.9)
Sequence of salvage treatment	
Systemic treatment → RT	17 (20.5)
Systemic treatment → RT → Systemic treatment	22 (26.5)
RT → Systemic treatment	15 (18.1)
No *peri*-RT systemic treatment	29 (34.9)

Abbreviations: SCC, Squamous cell carcinoma; N/A, not available; CCRT, concurrent chemoradiotherapy; RT, radiotherapy; EQD_2, equivalent dose of 2 Gy; LN, lymph node; MDRT, Metastasis-directed radiotherapy; SABR, stereotactic ablative radiotherapy; CPS, combined positive score; PD-L1, programmed death ligand 1; ICI, Immune checkpoint inhibitor.

intrapelvic and liver lesions. Dose-fractionation schedules for MDRT varied according to lesion characteristics, ranging from 5 to 20 Gy per fraction delivered in 1–5 fractions. The median overall treatment time, defined as the interval from the first to the last radiotherapy fraction, was 8 days (range, 0–20 days). Dose-fractionation prescription frequencies and dosimetric parameters of all treated lesions are summarized in **Supplementary Table 1**. The most commonly used regimen was 24 Gy delivered in 3 fractions. The median maximum prescribed dose of MDRT sites per patient in EQD_2 was 40.0 Gy (range, 29.8–125.0).

Systemic therapy was administered in the majority of patients. The predominant systemic treatment regimen was cytotoxic chemotherapy (42 patients, 50.6%) including bevacizumab, paclitaxel, and cisplatin, followed by immune checkpoint inhibitors (ICI) (15 patients, 18.1%), including pembrolizumab or nivolumab. Regarding treatment sequencing, systemic therapy was administered before MDRT in 17 patients (20.5%), both before and after MDRT in 22 patients (26.5%), and after MDRT in 15 patients (18.1%). Baseline patient and disease characteristics stratified using salvage systemic therapy are summarized in **Supplementary** Table 2.

Treatment outcomes

The median follow-up duration for the entire cohort was 20 months. The local control rate of MDRT target lesions, defined as complete response, partial response, or stable disease, was 60.8% (101 of 166 evaluable lesions). Representative MDRT plans for lung (Fig. 1A), mediastinal LN (Fig. 1B), pelvic peritoneal (Fig. 1C), and uterine body lesions (Fig. 1D) are shown. When failure patterns were classified according to their relationship with the MDRT treatment field, the predominant pattern of failure was out-of-field failure alone (45 patients, 54.2%), whereas combined in-field failure and out-of-field failure occurred in 38.6% of patients (Fig. 2).

The 2-year PFS and OS rates were 14.5% and 62.9%, respectively (Fig. 3). In the univariate analysis for PFS, patients with favorable RT target response demonstrated significantly improved outcome, which was the only significant factor in the multivariable analysis for PFS. In the univariate analysis for OS, patients with favorable oligometastatic disease classification, including induced oligorecurrence, metachronous oligorecurrence, and repeat oligorecurrence, showed a 2-year OS rate of 71.7%, compared with 45.6% in the unfavorable subgroup ($p = 0.011$). Moreover, patients with favorable RT target response showed a significantly higher 2-year OS rate (76.7%) than those with an unfavorable response (45.1%, $p = 0.003$). No other clinical or treatment characteristics including usage of systemic treatment (**Supplementary Fig. 1**) were significantly associated with OS. In the multivariable analysis, unfavorable oligometastatic disease classification and unfavorable RT target response emerged predictors of unfavorable OS (Table 2). Among all RT courses, MDRT was only occasionally associated with acute grade $\leq$ 2 adverse events, which varied according to the treatment site, whereas late adverse events were rare. No grade 3 or higher toxicities were observed (Table 3).

Discussion

In this study, we evaluated the clinical outcomes of MDRT in a notable number of patients with OCC. MDRT achieved favorable outcomes with minimal toxicities, while disease progression predominantly occurred outside the irradiated fields. The systemic treatment landscape for recurrent or metastatic cervical carcinoma has evolved rapidly, including cytotoxic chemotherapy [13,14] and immune checkpoint inhibitors (ICI) [15,16]. Alongside these advances, the role of MDRT,

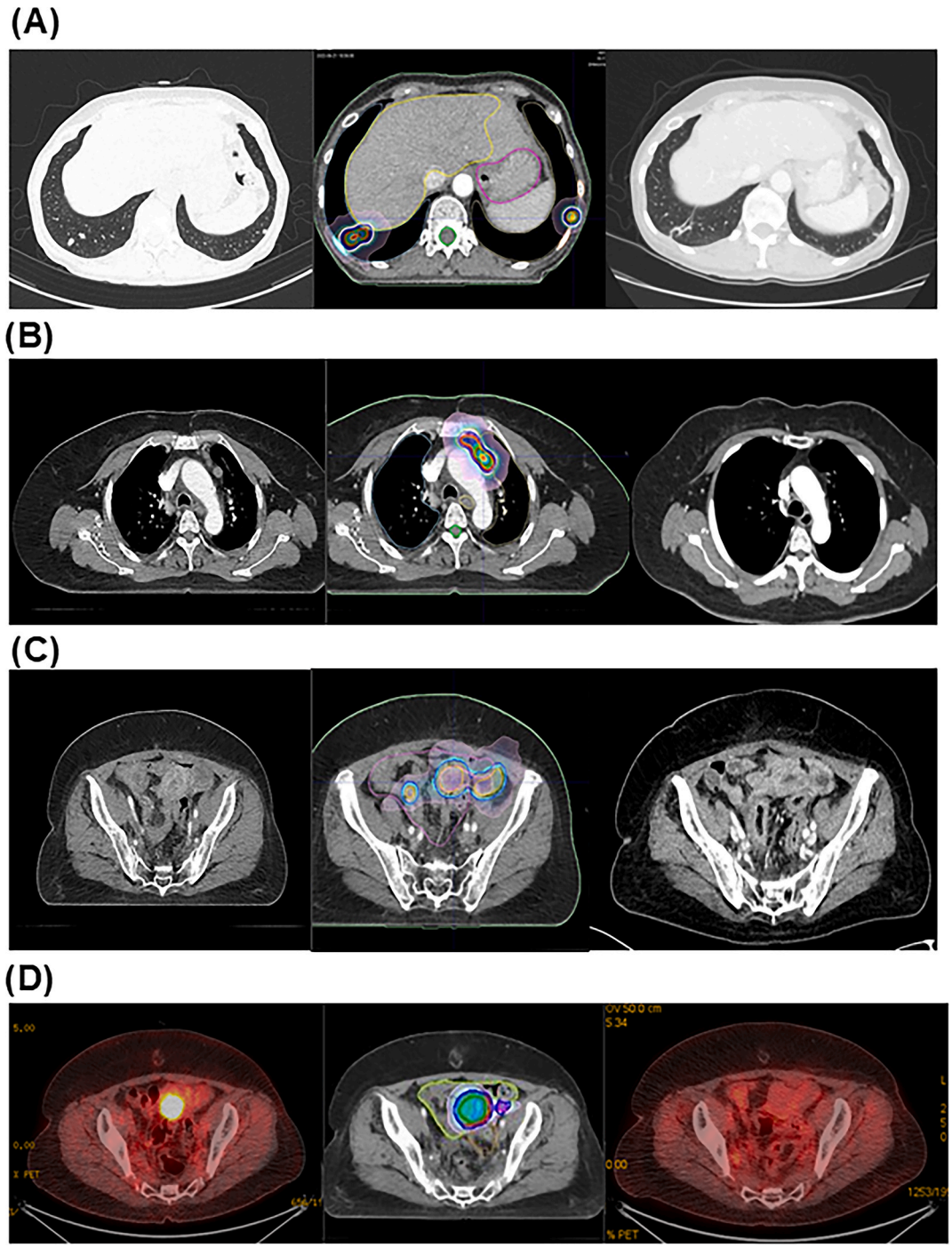

Fig. 1. Representative imaging of stereotactic ablative radiotherapy (SABR) in patients with oligometastatic cervical carcinoma. For each case, images are shown in the following order: pre-SABR (left), SABR isodose distribution (middle), and post-SABR imaging at 6 months (right). Cases in (A) lung, (B) mediastinal lymph nodes, (C) pelvic peritoneum, and (D) uterine body lesions.

including SABR, has gained increasing attention due to its ability to deliver highly conformal, short-course treatment that can be readily integrated between systemic therapy cycles. The present study represents one of the largest reported cohorts of OCC patients treated with MDRT in a real-world clinical setting.

Our results demonstrate that patients with favorable RT target response and oligometastatic disease classifications experienced significantly better OS following MDRT. Radiologic response to RT has been shown as a significant prognostic factor after MDRT [17], and a recent multicenter study has suggested repeat oligometastasis as a favorable subtype in breast cancer [18]. However, their prognostic significances have not yet been specifically evaluated in OCC [17,19]. Consistent with our findings, repeat oligometastasis and oligorecurrences arising during systemic treatment–free intervals, have been associated improved prognosis [12], reflecting their favorable tumor biology. In such OCC patients, our findings suggest that MDRT may provide benefit beyond local tumor control by contributing to prolonged disease control and survival.

In contrast, patients with unfavorable oligometastatic subtypes exhibited poorer outcomes, biologically plausible given that such scenarios often arise during systemic therapy and may reflect treatment-resistance. Nevertheless, our findings suggest that MDRT may still

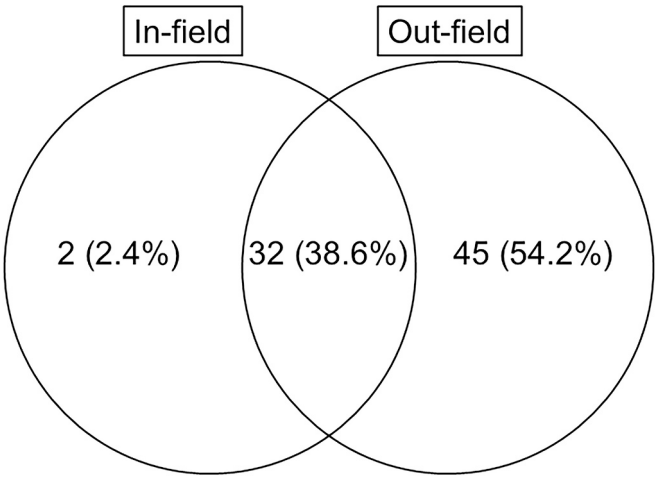

Fig. 2. Patterns of failure following stereotactic ablative radiotherapy in patients with oligometastatic cervical carcinoma.

provide clinical benefit in these settings by achieving durable local control of resistant lesions and allowing continuation of otherwise effective systemic therapy under multidisciplinary management. Recent studies demonstrated the utility of metastasis-directed approaches in unfavorable oligometastatic scenarios, including repeat oligoprogression [20], induced oligopersistence [21], and induced oligoprogression [22]. In such repeat oligometastatic settings, conventional survival endpoints may not fully capture the benefit of MDRT, where endpoints such as freedom from subsequent systemic therapy line [18] may better reflect improved quality of life of patients, which should be investigated in future studies.

Several factors may have contributed to the lower local control rate observed in this study compared to other studies [5,17,19]. Although doses corresponding to biologically equivalent doses of $\geq$ 100 Gy have been associated with superior local control in other oligometastatic settings [23,24], such dose escalation is often not feasible in OCC. First, many metastases in OCC occur within previously irradiated pelvic or *para*-aortic nodal regions, which are routinely included in definitive radiotherapy for cervical carcinoma [17,19]. Second, nodal oligometastases typically occur close to critical OARs, particularly the small bowel and duodenum, limiting full target coverage. Accordingly, PTV dose coverage was frequently compromised, as intended from our planning strategy allowing the PTV boundary dose to be as low as 50% of the prescription dose. Finally, the main goal of our MDRT was to maintain effective systemic therapy and delaying regimen changes rather than

Table 2
Multivariate analysis of the prognostic factors for survival outcomes in patients with oligometastatic cervical carcinoma.

Prognostic Variables	2-year progression-free survival			2-year overall survival		
	HR	95% CI	p-value	HR	95% CI	p-value
Age ($\geq$54 vs. < 54)	1.18	0.73–1.90	NS	1.81	0.81–4.05	NS
Pathology (Others vs. SCC)	1.20	0.70–2.05	NS	2.22	0.99–4.98	NS
Oligometastatic classification (unfavorable vs. favorable)	0.98	0.59–1.63	NS	2.64	1.21–5.75	0.015
Site (Others vs. LN)	1.47	0.86–2.54	NS	0.44	0.17–1.17	NS
Highest prescribed EQD_2 (<60 vs. $\geq$ 60)	1.38	0.74–2.57	NS	0.62	0.27–1.42	NS
RT response (unfavorable vs. favorable)	2.36	1.43–3.91	<0.001	3.94	1.68–9.26	0.002

Abbreviations: CI, confidence interval; SCC, Squamous cell carcinoma; CPS, Combined positive score; PD-L1, Programmed Death-Ligand 1; LN, lymph node; EQD_2, equivalent dose of 2 Gy; NS, not significant.

Table 3
Acute and late treatment-related toxicities.

Toxicities per RT course (N = 146)	Any (events)	G1	G2	≥G3 (events)
Acute toxicities				
Abdominal pain	1 (0.9%)	1 (0.9%)	0 (0.0%)	0 (0.0%)
Anorexia	11 (9.6%)	6 (5.3%)	5 (4.4%)	0 (0.0%)
Urinary frequency	11 (9.6%)	8 (7.0%)	3 (2.6%)	0 (0.0%)
Diarrhea	5 (4.4%)	3 (2.6%)	2 (1.8%)	0 (0.0%)
Productive cough	2 (1.8%)	2 (1.8%)	0 (0.0%)	0 (0.0%)
Fatigue	10 (8.8%)	8 (7.0%)	2 (1.8%)	0 (0.0%)
Nausea	7 (6.1%)	3 (2.6%)	4 (3.5%)	0 (0.0%)
Late toxicities				
Pulmonary fibrosis	1 (0.9%)	1 (0.9%)	0 (0.0%)	0 (0.0%)
Rectal bleeding	6 (5.3%)	6 (5.3%)	0 (0.0%)	0 (0.0%)
Proctitis	1 (0.9%)	1 (0.9%)	0 (0.0%)	0 (0.0%)
Cystitis	5 (4.4%)	5 (4.4%)	0 (0.0%)	0 (0.0%)
Urinary incontinence	3 (2.6%)	3 (2.6%)	0 (0.0%)	0 (0.0%)
Radiation pneumonitis	3 (2.6%)	0 (0.0%)	3 (2.6%)	0 (0.0%)

Abbreviations: RT, radiotherapy.

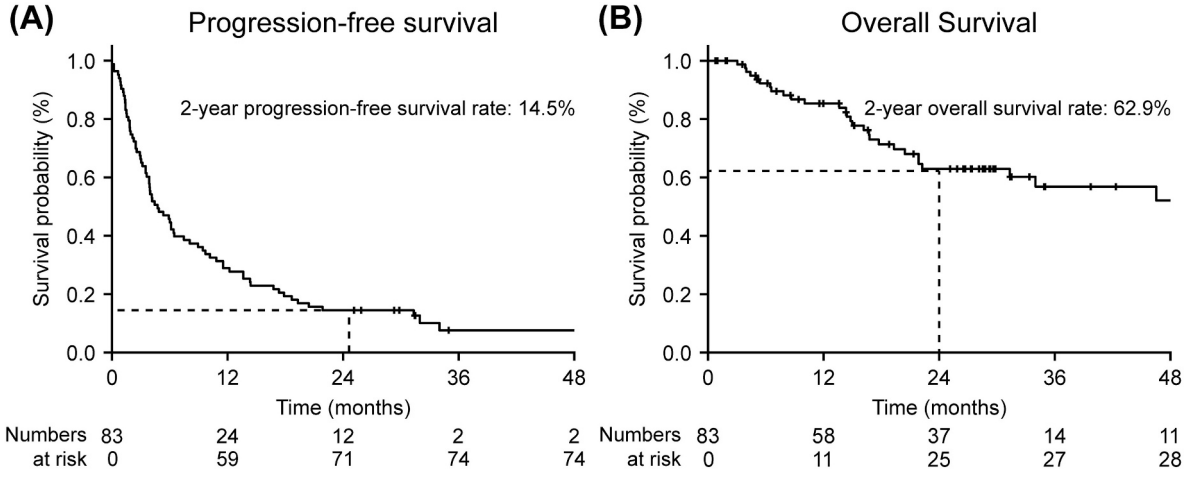

Fig. 3. Kaplan–Meier curves for (A) progression-free survival and (B) overall survival in patients with oligometastatic cervical carcinoma.

pursuing aggressive lesion ablation at the expense of increased toxicity, with the intention of preserving the option for repeated MDRT in subsequent oligometastasis. Notably, we did not experience any grade 3 or higher toxicities, and OS outcomes were comparable to those reported in studies achieving higher local control [5,17,19], suggesting that our MDRT strategy optimized for the clinical pattern of OCC may remain clinically meaningful in selected patients.

A notable clinical feature of OCC is the tendency for some patients to experience repeated episodes of oligometastatic disease. In our cohort, nearly one-third of patients underwent multiple courses of MDRT following multidisciplinary evaluation. To our knowledge, this is the first study to report the use of repeated MDRT for recurrent episodes of oligometastatic disease. To accommodate the possibility of repeated treatment, our institutional approach favored moderate-dose fractionation SABR rather than single-fraction, high-dose SABR, particularly when lesions were adjacent to critical OARs. As previously mentioned, this approach successfully minimized normal tissue injury and preserved the feasibility of subsequent MDRT after adequate recovery periods. The frequent use of multiple MDRT courses in our cohort supports the clinical practicality of this approach in selected patients. This approach aligns with emerging evidence suggesting that comprehensive treatment of multiple metastatic sites may be associated with improved disease control in selected patients with oligometastatic disease [25,26].

In this study, the use of salvage systemic therapy was not associated with significant differences in PFS or OS. Although this finding may seem counterintuitive, it likely reflects the bias from patient characteristics. Patients managed without systemic therapy more frequently presented with nodal oligometastatic disease and belonged to favorable ESTRO–EORTC subtypes, both of which are associated with more indolent tumor behavior and improved prognosis [27,28]. Consistently, radiotherapy response in this subgroup was generally favorable. In our multidisciplinary practice, patients demonstrating indolent disease progression are often managed with MDRT and surveillance without systemic therapy, which may explain the unbalanced patient characteristics and comparable survival outcomes observed between the groups.

Several limitations of this study should be acknowledged. First, the single-institution retrospective design introduces potential selection bias, and treatment decisions were influenced by multidisciplinary clinical judgment, which may limit the generalizability of our findings. Second, survival outcomes were inevitably influenced by heterogeneity in systemic therapy regimens and treatment sequencing, which represents a critical factor in treatment outcomes of oligometastatic disease managed with MDRT and complicates attribution of survival benefit solely to MDRT [26]. Third, although the analysis was restricted to SABR-treated patients, the delivered radiation dose may have been insufficient to achieve fully ablative intent in some cases, largely due to the proximity of metastatic lesions—particularly nodal targets—to critical organs at risk such as the small bowel and duodenum, which constrained dose escalation. Fourth, despite the usage of EQD_2 for dose comparison, the limitations of the linear–quadratic model at high fractional doses [29] restrict precise biological equivalence across different dose–fractionation schedules. Also, the significance of PD-L1 expression in MDRT for OCC could not be definitively assessed due to limited availability of PD-L1 data, warranting further investigation with systematic biomarker evaluation in larger cohorts, particularly in the context of combination with ICIs [30]. Finally, the significance of ESTRO-EORTC oligometastatic disease should be interpreted with caution as there are only a limited number of patients in each subgroup. Despite these limitations, the present study is strengthened by its relatively large cohort size for this rare clinical scenario and by its comprehensive analysis of treatment outcomes, toxicities, and prognostic factors.

Conclusions

In conclusion, MDRT using SABR was safely delivered to patients with OCC and achieved durable local control with minimal toxicity. The ESTRO-EORTC oligometastatic disease classification was significantly associated with OS, providing clinically relevant insights into patient selection for MDRT. Our results suggest that MDRT may be beneficial under multidisciplinary discussion for carefully selected OCC patients. Prospective studies are warranted to validate these findings and to further define the role of SABR and patient selection criteria for MDRT in the management of OCC.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work, the authors used ChatGPT (OpenAI) in order to assist with English language editing and improve clarity and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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CRediT authorship contribution statement

Won Hee Lee: Writing – original draft, Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Project administration, Data curation, Conceptualization. **Sangjoon Park:** Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Visualization, Conceptualization. **Chan Woo We:** Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Visualization, Conceptualization. **Yong Bae Kim:** Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Visualization, Conceptualization.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ctro.2026.101134.

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