Original Article

Enhancing palliative care in vulnerable patients: Robot-assisted radiofrequency ablation for multiple spinal metastases – Technical insights and preliminary outcomes

ABSTRACT

Background: Radiofrequency thermal ablation (RFA) coupled with vertebroplasty or kyphoplasty offers a minimally invasive, safe, and efficacious approach to palliate polymetastatic spine disease, particularly in medically fragile individuals. However, the application of robotic assistance to RFA for spinal metastases remains unexplored. This study elucidates the technical viability of robot-assisted RFA combined with vertebroplasty in patients afflicted by multiple spinal metastases and presents preliminary outcomes. An illustrative case was also presented.

Materials and Methods: Ten patients aged over 65 years with multiple vertebral metastases were enrolled in this study. Preoperatively, patients exhibited a median Visual Analog Scale (VAS) pain score of 6 and a Median Oswestry Disability Index (ODI) score of 58%. From February 2021 to April 2022, all patients underwent RFA, followed by vertebroplasty for spinal metastases. Surgical procedures were executed using the ExcelsiusGPS® robotic platform.

Results: Patients experienced substantial pain relief, with a median VAS score of 2.5 at 24 h postoperatively (Δ −3.5; $P < 0.001$) and a median VAS score of 2 at 1 month postoperatively (Δ −4; $P < 0.001$). All patients were discharged on the first postoperative day and continued their oncological treatments. In addition, the median ODI score at 1 month postoperatively was 34% (Δ −24%; $P = 0.006$), indicating an enhanced quality of life and a satisfactory impact on daily activities. No procedural or postoperative complications were documented.

Conclusions: This case series represents the inaugural successful application of robot-assisted RFA in conjunction with concurrent vertebroplasty/kyphoplasty. Our preliminary experience demonstrates that patients with oligo- and polymetastatic conditions can derive benefits from this minimally invasive intervention, characterized by rapid postoperative recovery and effective short- to medium-term pain management, without encountering complications.

Keywords: Elderly, radiofrequency thermal ablation, robotics, spinal metastasis, vertebroplasty

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INTRODUCTION

Approximately 50% of cancer patients develop bone metastases during their illness, with a median survival time of 8.5 months after diagnosis.[1,2] The spine is the most common site of metastatic bony localization. In these patients, the disease typically causes severe pain and spinal instability, often leading to palliative care as the primary

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goal of treatment. Several minimally invasive techniques have recently been developed to address these issues, including radiofrequency ablation (RFA), radiosurgery, and vertebroplasty, all of which have a positive impact on the quality of life of patients.[3-7] Among these techniques, radiofrequency ablation (RFA) uses alternating current to generate localized heating and necrosis of tumor tissue while preserving healthy bone. The concept of using RFA for palliating vertebral metastases was first proposed by Rosenthal *et al*. in 1992.[8-12] Since then, numerous reports have demonstrated the effectiveness of multiple RFA procedures in oligometastatic patients (i.e., those with fewer than five levels of metastases) who benefited from their initial procedure.[13] However, the literature on treating polymetastatic patients (i.e. those with five or more levels of metastases) remains limited due to the complexity of treatment decisions that depend on various aspects of the primary disease and spine involvement.[13] Patients with multiple spine metastases are rarely surgical candidates and pose challenges for radiotherapy. Robotic assistance may offer solutions to some of the major issues in these patients, such as enabling a quicker workflow, superior precision, minimally invasive surgical approaches, reduced blood loss, and rapid patient mobilization. While robotics is currently mainly applied to spinal fixation procedures, its application in treating spinal metastases has not been reported in the literature yet.[14] The aim of this study is to present the technical feasibility of this approach and analyze the potential advantages and drawbacks of robot-assisted RFA techniques in patients affected by multiple spinal metastases.

MATERIALS AND METHODS

Patients selection

A retrospective single-center study was conducted, enrolling patients aged 65 years or older, who were treated with RFA (OsteoCool™, Medtronic), followed by vertebroplasty for spinal metastases, from February 2021 to April 2022. Surgical procedures were performed using the ExcelsiusGPS® (Globus Medical, Inc., Audubon, Pennsylvania) robotic navigation platform. Patients with a preoperative Karnofsky Performance Status (KPS) score below 60 were excluded, as were those who received alternative treatment at the same spinal levels. The indications for the procedure are an essential aspect of the study. The treatment was primarily considered for patients with painful spinal metastases, limited response to conservative management, a KPS score above 60, and a minimum preoperative Visual Analog Scale (VAS) pain score of 4. All patients underwent preoperative thoracic-lumbosacral computed tomography (CT) and magnetic resonance imaging (MRI) scans, and the number of thoracolumbosacral spine lesions was categorized as "oligometastatic" if there were five or fewer lesions and "polymetastatic" if there were more than five lesions, following the classification proposed by Barzilai *et al*. in 2019.[15] Preoperative data included age, sex, number and level of lesions, recursive partitioning analysis (RPA) scoring system for patients with spinal metastases, Tomita scoring system, Spine Instability Neoplastic Scale (SINS), Bilski classification of epidural spinal cord compression, preoperative pain assessed by the VAS score (minimum score of 4), disability, and quality of life measured using the Oswestry Disability Index (ODI) questionnaire [Table 1]. A total of 10 patients, including 5 men (50%) and 5 women (50%), with a median age of 71.5 years (range: 66–80 years), 8 with oligometastatic (<5) and 2 with polymetastatic (≥ 5) vertebral lesions from primary tumors located in other sites, were selected. These patients had a median preoperative VAS score of 6 and a median preoperative ODI score of 58%. These parameters, except for the ODI questionnaire, were evaluated 24 h postoperatively and 1 month after the surgical procedure. Complications related to the surgical procedure were also assessed, including sphincter incontinence, sensorimotor deficits, heat radiculopathies, vascular injuries, and cerebrospinal fluid leaks. This study did not require IRB/ethics committee approval, and patient consent was obtained before the procedure. Statistical analysis was conducted using the paired *t*-test, and data were analyzed using GraphPad software (GraphPad Prism version 6.0, GraphPad Software Inc., New York City, New York, U.S).

Case presentation

We present the case of a 77-year-old female who was admitted to our institution with a diagnosis of polymetastatic spinal localization of breast cancer. An MRI revealed vertebral involvement at the thoracic and lumbar levels, specifically at Th9, Th10, Th11, L1, L2, and L3 with spinal cord compression noted at the Th9-Th11 level [Figure 1]. Upon neurological examination, the patient exhibited a Modified Rankin Scale score of 3/5, indicating paraparesis and diffuse numbness and weakness in both legs.

Surgical procedure

The surgical intervention involved a complex procedure for the patient, which included radiofrequency ablation (RFA) and O-arm guided vertebroplasty/kyphoplasty at multiple vertebral levels, namely, Th9, Th10, Th11, L1, L2, and L3. A preoperative plan was devised for the positioning of the RFA probe [Figure 2].

The surgical approach employed in this case was a monoportal approach with a convergent trajectory. In addition, microdecompression was performed at the Th9-Th11 levels. The surgery began with the patient in

Table 1: Visual Analog Scale score and Oswestry Disability Index score evaluation, recursive partitioning analysis scale, Tomita score, Spine Instability Neoplastic Scale, and Bilsky classification

Patient number	Primary tumor type	Age	Gender	Number of lesions	Metamers involved	RPA	Tomita	SINS	Bilski
1	Prostate	66	Male	3	L1-L2-L3	2	3	10	1[a]
2	Prostate	72	Male	2	T12, L3	2	3	6	1[a]
3	Prostate	69	Male	2	T11, T12	2	3	11	0
4	Lung	75	Female	3	L1, L4, L5	2	6	8	0
5	Breast	77	Female	6	T9, T10, T11, L1, L2, L3	2	3	9	2
6	Prostate	68	Male	6	T10, T11, T12, L3, L4, L5	2	3	11	0
7	Breast	67	Female	3	L1, L2, L5	2	3	10	1[a]
8	Breast	72	Female	2	T12, L4	2	3	10	0
9	Breast	71	Female	2	L1, L2	2	3	10	0
10	Prostate	80	Male	2	L1, L5	2	3	8	0

RPA – Recursive partitioning analysis; SINS – Spine Instability Neoplastic Scale

Figure 1: Preoperative spine magnetic resonance imaging sagittal images documented vertebral metastatic involvement at the thoracic and lumbar levels, specifically at Th9, Th10, Th11, L1, L2, and L3 with spinal cord compression at the Th9-Th11 level

the prone position, and a reference point was attached to the Th8 spinous process. Before the actual procedure, an intraoperative three-dimensional (3D) scan was conducted to provide a detailed visualization of the patient's anatomy [Figure 3].

This step was crucial for planning and guiding the subsequent surgical steps. The authors utilized a robot-assisted, minimally invasive approach for the radiofrequency ablation (RFA) part of the procedure. They employed the ExcelsiusGPS® Robotic Navigation Platform and intraoperative cone-beam CT guidance using the O-arm II by Medtronic [Figure 4].

This advanced technology allowed for precise navigation and monitoring throughout the surgery. The robotic system played a crucial role in ensuring the safety and precision of the procedure. It provided real-time monitoring and computer-aided navigation, allowing for the exact tracking of the instruments' positions during the surgery [Figure 5].

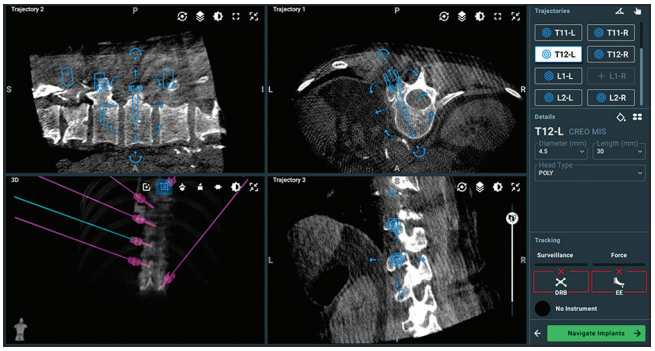

Figure 2: Preoperative planning with ExcelsiusGPS® Robotic Navigation Platform

The RFA probe, which was used for the ablation, was carefully guided into place with the assistance of guide wires and real-time navigation. Another two-dimensional/3D scan using cone-beam CT was conducted to confirm the probe's accurate placement within the targeted vertebral level [Figure 6].

For the ablation itself, a 10 mm bipolar probe (OsteoCool™, Medtronic) was employed. This probe had the capability to create an ablation zone of 17–13 mm, effectively covering most of the affected vertebral body. Importantly, the use of real-time navigation during the ablation procedure ensured that the thermal ablation was performed at a safe distance from nervous structures, enhancing the overall safety of the surgery. In conclusion, the combination of robotic assistance and the O-Arm II with 3D planning and real-time navigation for the RFA procedure proved to be of immense value. It not only enhanced precision but also significantly contributed to the safety of the surgical intervention, particularly in a delicate area like the spine.

Postoperative course

Following the surgical intervention, the patient was closely monitored for her postoperative recovery. The VAS score for pain was assessed both before and after the procedure to

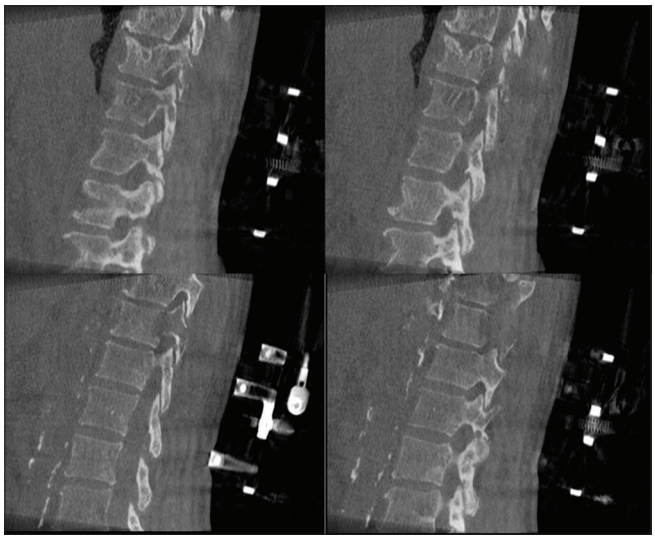

Figure 3: Intraoperative three-dimensional scan sagittal images with O-arm II provided a detailed visualization of the patient's anatomy and levels to treat

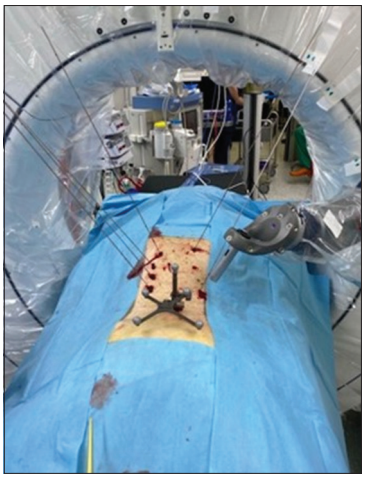

Figure 5: Intraoperative picture showing multilevel skin incisions and Kirschner wire positioning after the robot-assisted procedure. Each level was treated using a robot-assisted monolateral approach, enabling the RFA procedure on vertebral bodies with a single incision for each level

evaluate the patient's pain level and response to treatment. In addition, she underwent a postoperative thoracolumbar CT scan with 3D reconstructions to assess the surgical outcomes and spinal alignment [Figure 7].

Comparison of Visual Analog Scale scores

The patient reported a preoperative VAS score for pain of 7/10, indicating moderate-to-severe pain. After the surgery, the patient's postoperative VAS score for pain was reduced to 2/10, indicating significant pain relief and improved comfort. This case presentation highlights the challenging clinical scenario, the surgical approach adopted, and the notable improvement in the patient's pain levels following the procedure. The reduction in the postoperative VAS score from 7 to 2 demonstrates the effectiveness of the intervention in

Figure 4: Surgical theater showing the combined use of the ExcelsiusGPS® Robotic Navigation Platform (left) and intraoperative cone-beam computed tomography guidance (O-arm II, Medtronic) (right)

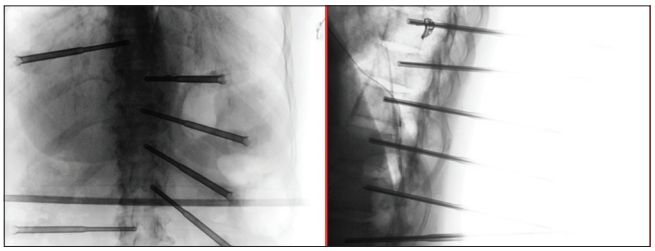

Figure 6: Intraoperative two-dimensional scan (AP and LL) with cone-beam computed tomography showing the position of the probes within the involved level

managing her spinal metastatic breast cancer and enhancing her quality of life.

RESULTS

A summary of the results is presented in Table 2.

A total of 10 patients with oligo- (six patients, 60%; <3 lesions) and polymetastatic disease (four patients, 40%; ≥3 lesions) at the thoracolumbosacral spine level underwent a combined treatment with robot-assisted RFA and subsequent vertebroplasty. Of these patients, 6 out of 10 presented Bilsky Grade 0 (bone-only disease), 3 out of 10 had Bilsky Grade 1a (epidural extension only, with no deformation of the thecal sac), and only one patient had Grade 2 (spinal cord compression, with cerebrospinal fluid visible around the subarachnoid space). Among the patients, 50% had a primary diagnosis of prostatic carcinoma, 40% had breast cancer, and 10% had lung carcinoma. Half of the patients had already undergone radiotherapy on at least one of the treated spinal segments. All patients were classified as RPA Class II, and none had spinal instability with a SINS score

Table 2: Pre- and postoperative pain (Visual Analog Scale) and functional Oswestry Disability Index scores

Patient number	Preoperative VAS score	24-h postoperative VAS score	1-month postoperative VAS score	Delta	Preoperative ODI (%)	1-month postoperative ODI score (%)	Delta (%)
1	8	2	2	−6	40	35	−5
2	6	3	4	−2	45	35	−10
3	6	1	2	−4	58	30	−28
4	5	1	2	−3	61	21	−40
5	7	2	2	−5	58	32	−26
6	9	3	2	−7	58	35	−23
7	6	3	2	−4	55	30	−25
8	5	2	2	−3	71	42	−29
9	7	3	1	−6	62	30	−32
10	6	3	1	−6	59	80	21

VAS – Visual Analog Scale; ODI – Oswestry disability index

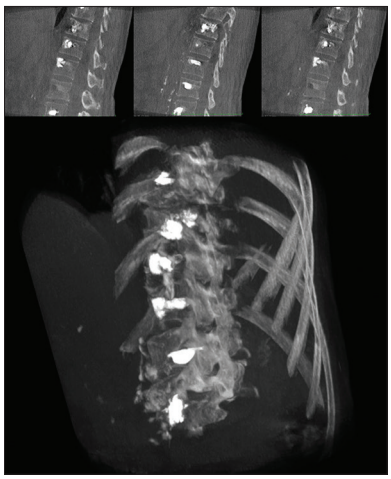

Figure 7: Postoperative spine cone-beam computed tomography with three-dimensional reconstruction

of ≤11. Nine out of 10 patients had a Tomita score of 3, with only one patient scoring 6, resulting in a median Tomita score of 3. Patients experienced significant pain reduction, with a median 24 h postoperative VAS score of 2.5 (Δ −3.5; $P < 0.001$) and a 1-month postoperative VAS score of 2 (Δ −4; $P < 0.001$). All patients were discharged on the first postoperative day to continue with adjuvant treatments. The median 1-month postoperative ODI score was 34% (Δ −24%; $P = 0.006$), indicating improved quality of life and satisfactory performance of daily activities. No intra- or postoperative complications were recorded in any of the enrolled patients.

DISCUSSION

In this study, we report the first case series of patients who were successfully treated for multiple vertebral metastases using RFA and vertebroplasty with robotic assistance for probe placement. Our preliminary experience has shown that even oligo- and polymetastatic elderly patients can benefit from this treatment with no peri- or postoperative complications, achieving optimal pain control in the short and medium term, ensuring a high rate of discharge on the first postoperative day, and maintaining good performance status. Vertebral metastases affect 70% of cancer patients[16] and have a significant impact on their quality of life. For isolated vertebral metastases at an early stage of the disease, radical surgical resection is recommended.[13] However, in cases of multiple vertebral involvement, palliative treatment is usually preferred to stabilize the spine and preserve neurological function.[16,17] RFA is a minimally invasive percutaneous surgical technique that uses an electrode to generate heat through alternating current, resulting in tumor necrosis and the destruction of local sensory nerve fibers.[8,9,10,14,16,18] This procedure can be performed multiple times with no risk of radiobiological exposure, providing immediate and significant pain relief.[14,17,19] Shawky AbdelGawaad *et al*.[20] examined in detail the association between radiofrequency ablation (RFA) and kyphoplasty in the treatment of painful spinal metastases. The results demonstrated a significant reduction in pain in 83.3% of the patients, as indicated by clinically significant improvement in VAS scores. Furthermore, there were no reported neurological complications related to RFA or cement extravasation into the spinal canal. The analysis of the results also revealed sustained improvement in pain at the 6-month follow-up. The combination of RFA and kyphoplasty appeared to be a safe and effective treatment option for painful osteolytic spinal metastases, providing pain relief and maintaining vertebral stability in a minimally invasive manner.

Recently, the use of robotic technology has gained popularity in spine surgery. The role of robotics is to automate complex procedural tasks that are usually subject to potential human errors, even in experienced surgeons.[21-23] In this study, we found that the robotic-assisted procedure could offer several advantages compared to the freehand procedure, including improved positioning of the insertion probe, reduced procedure time, decreased blood loss, and reduced radiation exposure.

In a recent comprehensive literature review, 25 studies investigating the use of robots in spinal surgery were identified. These studies encompassed 18 retrospective studies, 7 prospective studies, and 4 randomized controlled trials (RCTs).[24] In these studies, the Gertzbein and Robbins System (GRS) was frequently employed to assess pedicle screw accuracy, with Grades A and B being deemed acceptable. Remarkably, robot-assisted pedicle screw placement consistently demonstrated a high level of accuracy across all the studies. Notably, the initial RCT conducted by Ringel *et al*.[25] reported a lower accuracy rate with the use of robots, but subsequent RCTs by Kim *et al*.[26] and Hyun *et al*.[27] showed similar accuracy between robotic and freehand placement methods. In contrast, other studies consistently indicated improved accuracy when using robotic assistance. For instance, a study by Roser *et al*.[28] observed that the robotic technique exhibited superior accuracy compared to standard freehand and navigated procedures. Indeed, the rate of pedicle screw mispositioning with freehand techniques is estimated to range from 4.9% to 13%,[29] the robotic-assisted procedure may approach a precision rate of 100%.[28] This high level of accuracy in probe insertion during robot-assisted RFA can help deliver thermal energy precisely to the lesion site, minimizing the risk of preoperative complications to the surrounding tissue. Shorter operation times, lower blood loss rates, and reduced radiation exposure are among the main benefits of robotic-assisted RFA, with preoperative planning facilitating the insertion of the transpedicular probe through a single preplanned incision without the need for additional intraoperative fluoroscopic scans.

The study by Lieber *et al*.[30] showed that robotic-assisted lumbar fusion did not yield a significant reduction in common short-term perioperative complications compared to conventional fusion, with the specific exception of screw mispositioning.

Furthermore, in our study, we observed a significant difference in surgical timing, with the robot-assisted procedure taking 45 min compared to 1 h for the freehand RFA procedure. A shorter operative time is associated with better patient outcomes and has cost implications for the facility.

CONCLUSIONS

In this study, we report the first case series of patients who were successfully treated for multiple vertebral metastases with RFA and vertebroplasty using robotic assistance for probe placement. Our preliminary experience has demonstrated that even oligo- and polymetastatic elderly patients can benefit from this treatment with no peri- or postoperative complications. This approach provides optimal pain control in the short and medium term, ensures a high rate of discharge on the first postoperative day, and maintains good performance status. This offers an additional treatment option, and further research with a larger patient cohort is warranted to validate its efficacy.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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