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CLINICAL STUDY

Radiofrequency ablation and vertebral augmentation for palliation of painful spinal metastases

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Abstract Radiofrequency ablation (RFA) and vertebral augmentation is an emerging combination therapy for painful osseous metastases that cannot be or are incompletely palliated with radiation therapy. Herein, we report our experience performing RFA and vertebral augmentation of spinal metastases for pain palliation. Institutional review board approval was obtained to retrospectively review our tumor ablation database for all patients who underwent RFA of osseous metastases between April 2012 and July 2014. Patient demographics, lesion characteristics, concurrent palliative therapies, and complications were recorded. Pre- and post-procedure mean worst pain scores 1 and 4 weeks after treatment were measured using the Numeric Rating Scale (10-point scale) and compared. During the study period, 72 RFA treatments of 110 spinal metastases were performed. Eighty one percent (89/110) of metastases involved the posterior vertebral body and 45 % (49/110) involved the pedicles. Vertebral augmentation was performed after 95 % (105/110) of ablations. Mean and median pre-procedure pain scores were 8.0 ± 1.9 and 8.0, respectively. Patients reported clinically significant decreased pain scores at both 1-week (mean, 3.9 ± 3.0; median, 3.25; $P < 0.0001$) and 4-week (mean, 2.9 ± 3.0; median, 2.75; $P < 0.0001$) follow-up. No major complications occurred related to RFA and there were no instances of symptomatic cement extravasation. Combination RFA and vertebral augmentation is a safe and effective therapy for palliation of painful spinal metastases, including tumor involving the posterior vertebral body and/or pedicles.

Keywords Radiofrequency ablation · Metastatic spine disease · Pain palliation · Vertebral augmentation

Introduction

Over 1.4 million Americans are diagnosed with cancer each year, and these patients are living longer due to advances in oncology treatments [1]. The majority of these patients will develop metastatic disease that in 40 % of cases involves the spine [2]. Though most patients are asymptomatic, spinal metastases can become painful due to neural compression, pathologic fracture, or incompletely understood biochemical mechanisms [3]. Tumor likely stimulates nociceptors by stretching the periosteum, producing nociceptor sensitizing tumor-derived cytokines (e.g. tumor necrosis alpha), and by inducing the production of nociceptor sensitizing cytokines by local leukocytes [4–6]. Pain is likely also caused by osteoclast-mediated bone destruction promoted by tumor-derived cytokines [7, 8]. Pain and impaired mobility related to spinal metastases result in depression, anxiety and overall decreased quality-of-life [9].

Radiation therapy is the standard of care for palliation of painful osseous metastases, but has several limitations. First, meta-analysis of 25 trials with 5,617 patients treated with radiation therapy for painful bone metastases found overall and complete response rates of 60 and 23 %, respectively [10]. Thus, most patients unfortunately do not experience complete pain relief, and a significant percentage of patients have no response. Second, while most patients experience at least partial pain relief within 14 days of radiation therapy, some patients may not respond for

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4–6 weeks [11]. Third, patients with longer life expectancies may experience recurrent symptoms after an initial response. The Dutch Bone Metastasis Study of patients surviving longer than 52 weeks reported pain progression in 49 % (387/789) of patients who responded to initial treatment [12]. The mean time to progression for these patients was 12 weeks. Retreatment of spinal metastases with radiation therapy is often not possible due to the risk of radiation myelopathy [13]. Finally, radiation therapy excludes patients from certain systemic chemotherapy clinical trials.

Combination radiofrequency ablation (RFA) and vertebral augmentation is a minimally-invasive option for treating painful osseous metastases that cannot be or are incompletely palliated with radiation therapy. The procedure involves placing a percutaneous needle within the tumor. High-frequency alternating current is passed through the needle, which causes frictional heating and necrosis of the surrounding tissue [14]. Cement is then instilled into the vertebral body for structural support. Ablation likely reduces pain directly by destroying periosteal nociceptors and indirectly by reducing tumor bulk [8]. Vertebral augmentation likely contributes to pain palliation by stabilizing fractured trabeculae, and may also prevent vertebral body collapse secondary to ablation or tumor infiltration [8]. The combined procedure can be performed in an outpatient setting under conscious sedation and requires minimal recovery. The purpose of this study was to determine the safety and efficacy of RFA and vertebral augmentation for palliation of painful spinal metastases.

Methods

Institutional review board approval was obtained to retrospectively review a tumor ablation database for all patients who underwent RFA of osseous metastases at our institution between April 2012 and July 2014. Recorded data included patient age and gender, primary tumor histology, and vertebra(e) treated. Pre-procedure imaging of each treated vertebra was reviewed to determine whether tumor involved the posterior vertebral body, eroded through the posterior vertebral body cortex, and/or involved one or both pedicles. Pre-procedure imaging was also used to estimate the volume of tumor within each vertebra, defined as the volume of marrow enhancement or T2-hyperintensity on MRI, increased ^{18}F-fluorodeoxyglucose (FDG) uptake on PET-CT, or osteolysis on multidetector CT, whichever was largest. Recorded treatment details included the number of ablations performed at each level, the total duration of ablation at each level, and whether vertebral augmentation and/or epidural or nerve root corticosteroid injections were performed after the ablation. Whether radiation therapy was delivered to the ablated vertebra(e) within 6 weeks prior to treatment was also recorded. This time-frame was chosen to avoid a potentially confounding delayed palliative response to radiation therapy, as some patients may not experience pain relief from radiation therapy until up to 6 weeks after treatment [11].

Patient selection

Patients were selected for RFA and vertebral augmentation by a multidisciplinary team of radiation and medical oncologists, interventional radiologists, and spine surgeons. The majority of patients had pain that was limiting their quality-of-life and was uncontrolled with opioid analgesics. The painful vertebral levels were determined by correlating physical examination with the presence of spinal metastases on cross-sectional imaging. When two or three contiguous vertebrae contained tumor, all vertebrae were treated, because pain from adjacent vertebrae cannot be reliably distinguished clinically. Treated patients also could not receive radiation therapy, had persistent or recurrent pain despite radiation therapy, or were treated with combination radiation therapy, RFA, and vertebral augmentation when tumor radiation-resistance was anticipated. Some patients were also treated with RFA for local control; these patients are included in this case series for complication rate assessment only. Exclusion criteria for RFA and vertebral augmentation included metastases that were entirely osteoblastic [15], associated with pathologic compression fracture with spinal instability [16], or causing metastatic spinal cord compression [17]. Tumor within 1 cm of the spinal cord or nerves was not a contraindication for RFA.

Percutaneous procedure

Written informed consent was obtained prior to all treatments. All treatments were performed under conscious sedation with fentanyl and midazolam. Under fluoroscopic- or CT-guidance, the periosteum was anesthetized, the vertebral body was accessed with a 10-gauge introducer cannula from a transpedicular approach, and a navigational osteotome was used to create one or more osseous channels. A uni- or bipedicular approach and the number of osseous channels created depending on the extent of tumor on pre-procedure cross-sectional imaging. The goal was to ablate the entire volume of marrow enhancement or T2-hyperintensity on MRI, increased FDG uptake on PET-CT, or osteolysis on multidetector CT, as well as an additional 3-mm margin to account for microscopic tumor spread [18].

Ablations were performed with the STAR Tumor Ablation System (DFINE; San Jose, CA). The ablation probe included with this system has an articulated distal

segment that is used to redirect the radiofrequency electrode into different portions of tumor throughout the vertebral body and pedicles, including the posterior central vertebral body [19] (Fig. 1). This probe also contains two thermocouples that permit real-time monitoring of temperatures 10 and 15 mm from the center of the ablation zone. Each individual ablation was performed until the thermocouple located 15 mm from the radiofrequency electrode reached 50 °C. Based on manufacturer thermal distribution curves, the dimensions of the ellipsoid ablation volume are 30 mm × 20 mm when the this thermocouple reaches 50 °C, and 20 mm × 13 mm when the thermocouple located 10 mm from the radiofrequency electrode reaches 50 °C [19]. Tumors that could not be completely treated by a single 30-mm × 20-mm ellipsoid ablation volume were treated with multiple overlapping ablations. Tumors confined to one half of the hemivertebral body were treated from a unipedicular approach by redirecting the radiofrequency probe into all portions of the tumor (Fig. 1). Tumors extending across the sagittal midline were treated with overlapping ablations from bipedicular approaches. During an individual ablation, the electrode was placed no closer than 10 mm from the posterior vertebral body wall, which is the maximum radius of the minor-axis of the ellipsoid ablation zone. When ablating near this threshold, an additional thermocouple was placed in the neural foramen. If the temperature in the neural foramen exceeded 45 °C, CO_2 or cooled 5 % dextrose in water was injected coaxially over the thermocouple for thermal protection [20]. In the majority of cases, vertebral augmentation was performed after RFA using the StabiliT Vertebral Augmentation System (DFINE; San Jose, CA). Cement was injected through the same working cannula(e) used for ablation. Central epidurals or selective nerve root injections of bupivacaine and a corticosteroid were performed for patients with radicular pain prior to or following the treatment.

Pain palliation and complication assessment

Pre- and post-procedure worst pain 1 and 4 weeks after treatment were measured using the Numeric Rating Scale (NRS), a validated self-reporting assessment [21] (Table 1). Pre-procedure pain was assessed on the day of treatment by a musculoskeletal radiology nurse coordinator. Post-procedure pain scores were obtained 1 and 4 weeks after treatment via telephone interviews with the same nurse coordinator. When multiple vertebrae were treated, pain scores were assigned to the treatment as a whole, rather than asking patients to assign a separate pain

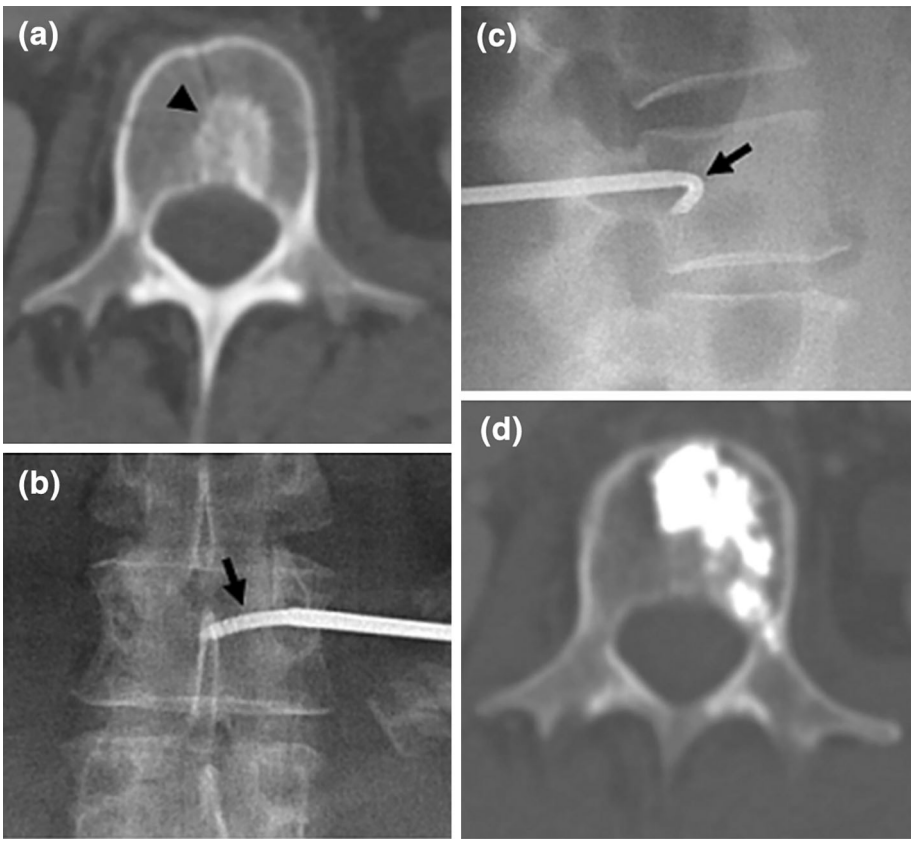

Fig. 1 51-year old woman with breast cancer and debilitating low back pain unrelieved with opioids. **a** Axial CT image shows a mixed lytic and blastic L1 metastasis (*black arrowhead*), which correlated with the location of her pain on physical examination. AP (**b**) and lateral (**c**) fluoroscopic images show the distal ablation probe curving into the central posterior vertebral body from a unipedicular approach (*black arrows*). Vertebral augmentation was then performed for fracture prophylaxis through the same working cannula (**d**). Her pain was completely relieved at 1- and 4-week follow-up

Table 1 Numerical rating scale for pain self-assessment

Rating	Pain level
0	No pain
1–3	Mild pain (little interference with ADLs)
4–6	Moderate pain (significant interference with ADLs)
7–10	Severe pain (unable to perform ADLs)

ADLs activities of daily living

score to each vertebral level. At the 4-week interview, patients were also asked about changes in pain medication usage and activity level (increased, decreased, or unchanged). After each procedure, patients were evaluated for evidence of complications, particularly new radicular pain or other manifestations of thermal nerve injury. Patient charts were also reviewed for evidence of complications related to the treatment.

For patients with pre-procedure NRS $\geq$4, the Mann–Whitney U test was used to compare pre- and post-procedure pain scores. Categorical treatment responses were also calculated with partial pain relief defined as $\geq$2-point pain score reduction and complete relief defined as post-procedure pain score $\leq$1 (7, 21–23). The percentages of patients reporting decreased, unchanged, or increased pain medication usage and activity level 4 weeks after treatment were also calculated. These calculations were also made for the subgroups of patients who (1) were not treated with radiation therapy within 6 weeks prior to RFA therapy, and (2) were not treated with radiation therapy within 6 weeks of treatment *and* did not receive an epidural or nerve root injection within 4 weeks of the treatment. For the subgroup of patients who underwent treatment of a single vertebral level, Spearman's rank correlation coefficient was calculated for the median pre-procedure tumor volume and median pain score reductions at 1 and 4 weeks, and a *t* test was performed to assess the statistical significance of the Spearman's rank correlation. The Mann–Whitney U test was used to compare median pain score reductions at 1 and 4 weeks reported by patients who underwent treatment of a single vertebra versus multiple vertebrae. For all statistical tests, a P value <0.05 was considered statistically significant.

Results

During the study period, 72 RFA treatments of 110 spinal metastases were performed. Patient demographics and primary tumor histologies are summarized in Table 2. The most common primary tumors were non-small cell lung cancer 24 % (17/72), breast adenocarcinoma 15 % (11/72), and renal cell carcinoma 13 % (9/72). Eighty one percent (89/110) of metastases involved the posterior vertebral body, 29 % (32/110) were associated with erosion of the posterior vertebral body cortex, and 45 % (49/110) involved the pedicles. Forty nine percent (54/110) of treated tumors were located in the thoracic spine and 51 % (56/110) were located in the lumbar spine. Within each vertebra, the mean number of ablations was 6.4 $\pm$ 3.1, and the mean total ablation time was 8 min and 32 s $\pm$4 min and 49 s. Vertebral augmentation was performed after 95 % (105/110) of ablations, in all cases through the same working cannula(e). Central epidurals or selective nerve root injections were performed as part of 43 % (31/72) of treatments. Thirty one percent (22/72) of treatments were to vertebrae that were also treated with radiation therapy within 6 weeks of RFA.

Table 2 Patient and tumor characteristics

Patient age (years)	68.4 $\pm$ 18.8
Men	39 % (28/72)
Women	61 % (44/72)
Primary tumor	
Breast adenocarcinoma	15 % (11/72)
Lung	28 % (20/72)
NSCLC	85 % (17/20)
SCLC	15 % (3/20)
Sarcoma	18 % (13/72)
Renal cell carcinoma	13 % (9/72)
GI adenocarcinoma	5.6 % (4/72)
Multiple myeloma	5.6 % (4/72)
Melanoma	5.6 % (4/72)
Other	9.7 % (7/72)

GI gastrointestinal, *NSCLC* non-small cell lung cancer, *SCLC* small cell lung cancer

Patients reported NRS scores $\geq$4 prior to 89 % (64/72) of treatments. These patients reported mean and median pre-procedure pain scores of 8.0 $\pm$ 1.9 and 8.0, respectively. Follow-up was available 1 week after all treatments, at which time patients reported clinically significant decreased pain scores (mean, 3.9 $\pm$ 3.0; median, 3.25; $P < 0.0001$). Categorically, 70 % (45/64) of patients reported at least partial and 23 % (15/64) reported complete pain relief at 1-week follow-up. Six patients (9.4 %; 6/64) subsequently died prior to the 4-week follow-up. The surviving patients at that time reported clinically significant decreased pain scores (mean, 2.9 $\pm$ 3.0; median, 2.75; $P < 0.0001$). Categorically, 78 % (45/58) of these patients reported partial and 45 % (26/58) reported complete pain relief. The 4-week follow-up pain scores corresponded with decreased pain medication usage in 31 % (18/58) of patients and increased activity in 50 % (29/58) of patients.

Forty three treatments (60 %; 43/72) were performed on patients with pre-procedure NRS scores ≥4 who did not receive radiation therapy within 6 weeks prior to RFA therapy. The pre-procedure mean and median pain scores for this subgroup were 7.9 ± 1.9 and 8.0, respectively. This subgroup reported clinically significant decreased pain scores at both 1 week (mean, 3.5 ± 3.0; median, 3.0; $P < 0.0001$) and 4 weeks (mean, 2.5 ± 2.8; median, 2.0; $P < 0.0001$) after treatment. Categorically, 77 % (33/43) of these patients reported at least partial and 26 % (11/43) reported complete pain relief 1 week after treatment. At 4-week follow-up, 54 % (21/39) of these patients reported at least partial and 41 % (16/39) reported complete pain relief. In this subgroup, 4-week follow-up pain scores corresponded with decreased pain medication usage in 31 % (12/39) of patients and increased activity in 46 % (18/39) of patients.

Twenty two treatments (31 %; 22/72) were performed on patients with pre-procedure NRS scores ≥4 who did not receive radiation therapy 6 weeks prior to RFA therapy *or* an epidural or nerve root corticosteroid injection within 4 weeks of RFA therapy. The pre-procedure mean and median pain scores for this subgroup were 8.6 ± 2.1 and 9.0, respectively. Clinically significant decreased pain scores were reported at 1-week (mean, 6.2 ± 2.1; median, 5.5; $P < 0.0001$) and 4-week (mean, 4.3 ± 3.4; median, 4.5; $P < 0.0001$) follow-up. Categorically, 64 % (14/22) of these patients reported at least partial pain relief at 1 week. At 4-week follow-up, 65 % (13/20) of these patients reported partial and 25 % (5/20) reported complete pain relief. In this subgroup, 4-week follow-up pain scores corresponded with decreased pain medication usage in 70 % (14/20) of patients and increased activity in 35 % (7/20) of patients.

Forty five patients (63 %; 45/72) underwent treatment of a single vertebra, 39 of whom (54 %; 39/72) reported pre-procedure NRS scores ≥4. The pre-procedure mean and median pain scores for this subgroup were 8.0 ± 1.8 and 8.0, respectively. In this subgroup, the mean and median pre-procedure tumor volumes were 16.3 ± 11.2 ml and 14.9 ml (range, 1.4–44.1 ml), respectively. There was not a statistically significant correlation between the pre-procedure tumor volume and median pain score reduction at 1-week ($\rho = -0.02$, $P = 0.89$) or 4-week ($\rho = -0.05$, $P = 0.78$) follow-up.

Twenty seven patients (38 %; 27/72) underwent treatment of multiple vertebrae, all of whom reported pre-procedure NRS scores ≥4. Seventy percent (19/27) of these patients underwent treatment of two vertebrae, six patients (22 %; 6/27) underwent treatment of three vertebrae, and two patients (7.4 %; 2/27) underwent treatment of four vertebrae. Patients who underwent treatment of multiple vertebrae reported pre-procedure mean and median pain scores of 8.5 ± 1.7 and 9.0, respectively, which were not significantly different compared to patients who underwent treatment of a single level ($P = 0.83$). Patients who underwent single level treatment reported mean and median pain scores of 2.1 ± 0.9 and 2.0 at 1-week and 2.6 ± 0.9 and 2.5 at 4-week follow-up. Patients who underwent treatment of multiple levels reported mean and median pain scores of 3.9 ± 2.6 and 4.0 at 1-week and 3.3 ± 3.2 and 3.0 at 4-week follow-up. Changes in median pain scores were not significantly different between patients who underwent treatment of a single vertebra versus multiple vertebrae at either 1-week ($P = 0.55$) or 4-week ($P = 0.41$) follow-up.

According to the Society of Interventional Radiology guidelines, there were no major complications in the follow-up period, such as permanent thermal nerve injury. Four patients (5.6 %; 4/72) reported post-procedure radicular pain. In all of these patients, ablation was performed within the pedicle, and the radicular pain resolved after one or two transforaminal nerve root corticosteroid injections. There were no instances of symptomatic cement extravasation. Sixty percent (3/5) of the radiofrequency ablated vertebrae that were not augmented fractured within the subsequent 12 months.

Discussion

In recent years, several small case series have reported decreased pain scores after RFA of osseous metastases [15, 22]. These include a multicenter series of 55 tumors, in which average pain intensity was reduced by 26.9/100 points at 4 weeks ($P < 0.0001$) and 14.2 points at 12 weeks ($P = 0.02$) after RFA [15]. However, this series included only 8 vertebral metastases (14.5 %; 8/55). Because of the complex anatomy and biomechanics of the spine, the safety and efficacy of ablating spinal metastases must be considered separately. Thirty four of the treatments in the present series were previously reported as part of a multicenter series by Anchala et al. [23] that included 96 radiofrequency ablations of 128 spinal metastases. Anchala et al. reported decreased patient pain scores both 1 week (7.51/10 ± 2.46 versus 1.73/10 ± 2.28; $P < 0.0001$) and 4 weeks (2.25/10 ± 2.44; $P < 0.0001$) after treatment. However, these results were limited by follow-up rates of 58 % (56/96) at 1 week and 86 % (83/96) at 4 weeks. Anchala et al. also did not perform subgroup analyses to account for the confounding palliative effects of radiation therapy or corticosteroid injections.

In the present case series, 110 spinal metastases were radiofrequency ablated as part of 72 consecutive treatments. Patients treated for pain palliation reported clinically significant decreased pain scores at both 1- and

4-week follow-up, including patients who did not also receive prior or concurrent radiation therapy or corticosteroid injections. This rapid pain palliation is a unique and important benefit of RFA for patients with short life expectancies, as palliative radiation therapy can take up to 6 weeks to produce relief [11]. These results are not compromised by follow-up bias, as pain scores were obtained 1 week after all treatments and only 6 patients (9.3 %; 6/64) died before the 4-week follow-up.

This case series also further illustrates that RFA of large metastases, including those located in the posterior vertebral body and pedicles, can be performed thoroughly and safely. The ablation probe used in this case series has an articulated distal segment that can be used to redirect the radiofrequency electrode into multiple portions of the vertebral body from a transpedicular approach, including the posterior central vertebral body (Fig. 1). The probe also contains two thermocouples located 10- and 15-mm from the electrode that permit real-time monitoring of individual ablation volumes, thus facilitating treatment of large tumors with overlapping ablations while maintaining a safe distance between the ablation volume and neural structures. Twenty six treatments in this series were previously included in a technical note describing these features [19]. In the present series, there was not a statistically significant correlation between pre-procedure tumor volume and magnitude of median pain score reduction at 1-week ($\rho = -0.02$, $P = 0.89$) or 4-week ($\rho = -0.05$, $P = 0.78$) follow-up. Additionally, 81 % (89/110) of treated tumors involved the posterior vertebral body, 36 % (32/89) of which had eroded through the posterior vertebral body cortex, and 45 % (49/110) also involved the pedicles. This intravertebral distribution reflects that of spinal metastases in general, which is due to the posteriorly located basivertebral vein serving as an entry point for hematogenous tumor spread [24]. Despite the proximity of tumor to the spinal cord and nerve roots, no major thermal nerve injuries occurred. Four pedicle ablations (12.5 %; 4/32) caused post-procedure radicular pain that resolved after one or two transforaminal nerve root corticosteroid injections. The ability to safely radiofrequency ablate tumor in the posterior vertebral body and pedicles is particularly important, because it is often difficult to deliver sufficiently high radiation doses to these areas due to the risk of radiation myelopathy [13].

Vertebral augmentation was performed after RFA in 95 % (105/110) of treatments in this case series. The five ablations that were not followed by vertebral augmentation were performed during our early experience with RFA. We now routinely instill cement after RFA through the same working cannula, and consider vertebral augmentation to be an integral part of the ablation procedure. When treating spinal metastases complicated by pathologic fracture, vertebral augmentation produces added pain relief, presumably by means of trabecular stabilization [25]. A multicenter randomized controlled trial of 129 neoplastic vertebral compression fractures treated with vertebral augmentation found an 8.3/24-point improvement in back-specific functional status 4 weeks after vertebral augmentation compared with 0.1 points with conservative management ($P < 0.0001$) [26]. When treating spinal metastases without an associated pathologic fracture, we perform vertebral augmentation for fracture prevention. In the placebo arms of several large, Phase 3 trials, pathologic vertebral compression fractures occurred in 39 % of patients with breast cancer, 22 % of patients with prostate cancer, and 22 % of patients with lung cancer or other solid tumors during 12, 15, and 21 months of follow-up, respectively [27]. Whether RFA further increases the risk of fracture is unknown; however, 60 % (3/5) of vertebral bodies in this series that were not augmented after RFA fractured in the subsequent 12 months. Additionally, the risk of vertebral augmentation is minimal, as we encountered no instances of symptomatic extravasation. Therefore, given that the potential benefits of performing vertebral augmentation after RFA exceed the risks, it is impractical and unnecessary to parse the palliative benefit of ablation and vertebral augmentation individually.

An inherent limitation of this and all studies that attempt to quantify the effectiveness of palliative therapy is the reliance on pain scores as an outcome measure. These scores are subjective and may be confounded by pain medication usage and the status of visceral metastatic disease and other medical conditions. To account for this, data regarding changes in pain medication usage and activity level were also obtained, which showed that decreased pain scores corresponded with decreased pain medication usage and increased activity in a proportion of patients. Other limitations of this study include that it is retrospective and the cohort was heterogenous in terms of primary tumor histology. Additionally, a follow-up period of only 4 weeks precludes evaluation of recurrent pain. Finally, although this is the first case series to provide subgroup analysis of RFA of spinal metastases not treated with radiation therapy or corticosteroid injections, the size of this subgroup was small ($n = 22$).

A multicenter, prospective clinical trial (NCT02225223) is recently underway which will expand upon the results of this retrospective study by measuring multiple short- and long-term clinically meaningful endpoints. Patients with spinal metastases will be treated with RFA and vertebral augmentation prior to or after failed radiation therapy. The primary outcome measure is pain relief 6 weeks after percutaneous treatment, as measured by the Brief Pain Inventory (BPI) worst pain score. Secondary outcome measures will be obtained at 6 months, and include

changes in quality of life (measured by the BPI Interference score), functional status (measured by the Functional Assessment of Cancer Therapy-G), and pain medication usage. Pre- and post-treatment imaging will also be obtained to assess radiographic local tumor control, which has ramifications for whether RFA may produce survival benefit and/or delay neurologic complications.

Conclusion

Combination RFA and vertebral augmentation is a safe and effective therapy for palliation of painful spinal metastases, including tumor involving the posterior vertebral body and/or pedicles. These results must be confirmed with future prospective clinical trials.

Conflict of interest JWJ is a speaker panelist and consultant for DFINE, Inc. ANW and TJG declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

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