J Neurosurg Spine 14:372–376, 2011

Balloon kyphoplasty in the treatment of metastatic tumors of the upper thoracic spine

Clinical article

Mohammed Eleraky, M.D.,[1] Ioannis Papanastassiou, M.D.,[1] Matthias Setzer, M.D.,[1,2] Ali A. Baaj, M.D.,[1] Nam D. Tran, M.D., Ph.D.,[1] and Frank D. Vrionis, M.D., Ph.D.[1]

[1]H. Lee Moffitt Cancer Center & Research Institute, Neurooncology Program and Department of Neurosurgery, University of South Florida College of Medicine, Tampa, Florida; and [2]Department of Neurosurgery, J. W. Goethe University, Frankfurt, Germany

Object. Balloon kyphoplasty has recently been shown to be effective in providing rapid pain relief and enhancing health-related quality of life in patients with metastatic spinal tumors. When performed to treat lesions of the upper thoracic spine, kyphoplasty poses certain technical challenges because of the smaller size of the pedicle and vertebral bodies. Fluoroscopic visualization is also difficult due to interference of the shoulder. The authors' objective in the present study was to evaluate their approach and the results of balloon kyphoplasty in the upper thoracic spine in patients with metastatic spinal disease.

Methods. Fourteen patients underwent kyphoplasty via an extrapedicular approach to treat metastatic tumors in the upper (T1–5) thoracic spine. Electrodiagnostic monitoring (somatosensory and motor evoked potentials) was used in 5 cases. Three levels were treated in 7 cases, 2 levels in 2 cases, and 1 level in 5 cases. In 3 cases access was bilateral, whereas in 11 cases access was unilateral. The procedure took an average of 25 minutes per treated level, and the mean amount of cement applied was 3 ml per level. Four patients were discharged from the hospital on the day of the procedure, and 10 patients went home after 24 hours.

Results. All patients exhibited marked improvement in mean visual analog scale scores (preoperative score 79 vs postoperative score 30, respectively) and Oswestry Disability Index scores (83 vs 33, respectively). The mean kyphotic angle was 25.03° preoperatively, whereas the mean postoperative angle was 22.65° ($p > 0.3$). At latest follow-up, the mean kyphotic angle did not differ significantly from the postoperative kyphotic angle (26.3°, $p > 0.1$).

No neurological deficits or lung-related complications (pneumothorax or hemothorax) were encountered in any of the patients. Polymethylmethacrylate cement extravasations were observed in 3 (10%) of 30 treated vertebral bodies without any sequelae. By a mean follow-up of 16 months, no patients had experienced an adjacent-level fracture.

Conclusions. Balloon kyphoplasty of the upper thoracic spine via an extrapedicular approach is an efficient and safe minimally invasive procedure that may provide immediate and long-term pain relief and improvement in functional ability. It is technically challenging and has the potential for serious complications. With a fundamental knowledge of anatomy, as well as an ability to interpret fluoroscopy images, one can feasibly and safely perform balloon kyphoplasty in the upper thoracic spine. *(DOI: 10.3171/2010.11.SPINE09909)*

Key Words • **upper thoracic spine** • **metastasis** • **kyphoplasty**

Vertebral compression fractures are frequently seen in cases of osteolytic or metastatic disease. They represent a major health care problem. Kyphoplasty, in pathological spinal fractures, improves QOL and function by alleviating pain and reducing the intake of oral and parenteral analgesia.[1,3,8,13]

In particular patients with middle and upper thoracic fractures suffer from pain and decreased lung function due to anterior height loss and kyphosis.[4,11,16]

Upper thoracic kyphoplasty may pose special challenges considering the relatively small pedicle size and severe angulations associated with kyphosis.[9,11,12]

The purpose of this retrospective study was to compare preoperative and postoperative pain intensity, QOL, and kyphotic angle in patients who underwent upper thoracic kyphoplasty to treat pathological fractures. Surgical nuances and potential pitfalls are also highlighted.

Methods

The authors undertook a retrospective study of 14 patients (6 women and 8 men; mean age 62 years, range 41–71 years) who underwent kyphoplasty for metastatic disease of the upper thoracic spine (30 levels overall). The mean follow-up period was 16 months (minimum 1 year). Patients with shorter follow-up were excluded to focus on the duration of the presumed improvement and to assess the effectiveness of the procedure in maintaining the kyphotic angle after surgery (before exclusion of pa-

Abbreviations used in this paper: MEP = motor evoked potential; ODI = Oswestry Disability Index; PMMA = polymethylmethacrylate; QOL = quality of life; SSEP = somatosensory evoked potential; VAS = visual analog scale; VB = vertebral body.

tients with a shorter follow-up, the number of patients was 23). Diagnosis was as follows: multiple myeloma in 6 patients; lung cancer in 3; breast cancer in 2; and melanoma, leiomyosarcoma, and bladder cancer in 1 each. Four patients underwent neoadjuvant and 4 underwent adjuvant radiosurgery to treat the affected level. The remaining patients had multiple myeloma, and radiation treatment was not performed.

Patients had vertebral compression fracture between T-1 and T-5, all due to malignancy. All patients suffered back and anterior chest pain that was aggravated by postural changes and was refractory to pain medication. We frequently obtained preoperative CT scans of the fractured VB, which were sagittally reconstructed to evaluate the posterior wall. Spinal MR imaging (T1-weighted, T2-weighted, and STIR sequences) was also conducted to detect VB edema and associated impending fractures.

Intraoperative SSEP and MEP monitoring was used in 5 cases with cord compression. As other authors suggest, we did not consider spinal canal encroachment a contraindication to the procedure.[8,23,24] Three levels were treated in 7 cases, 2 levels in 2 cases, and 1 level in 5 cases. Three cases were accessed bilaterally. The procedure took an average of 25 minutes for each level, and the mean amount of cement applied at each level was 3 ml. An 11-gauge needle was used in 6 patients and an 8-gauge needle was used in 8 cases. The diagnosis of bone metastasis was confirmed by bone biopsy during surgery. Four patients were discharged from the hospital on the day of the procedure, and 10 patients went home after 24 hours.

All patients underwent clinical evaluation and plain spinal radiography before and after surgery, as well as at 3, 6, and 12 months postoperatively (thereafter, it was performed at 6-month intervals). Pain was assessed using a VAS, and functional capacity was assessed using the ODI. The VAS scores were determined by the patients, who marked a point on a 0–100 line that represented their average perception of pain (0 = no pain; 100 = worst possible pain). It was also confirmed by the spine fellow (M.E.). The degree of kyphosis was measured and compared on lateral standing plain radiographs/CT scans. We estimated the local kyphotic angle (superior and inferior endplates of affected vertebrae) for more accurate results. Two independent fellows (M.E. and I.P.) evaluated the radiographs. Finally the volume of injected cement/cement extravasation was recorded, and any procedure-related complications were analyzed.

Statistical Analysis

The results of VAS, ODI, kyphotic angle, and vertebral height measurement before and after the procedure were compared and analyzed using a paired t-test (SPSS, version 14.0). Probability values less than 0.05 were considered statistically significant.

Surgical Technique

Procedures were performed after induction of general anesthesia, and biplanar fluoroscopy was used.

The most important factors for successful kyphoplasty outcome were correct positioning of the patient during the procedure and a good view of the VB. Shoulders can prevent an adequate lateral view, and therefore an appropriate-height pillow was placed under the patient's chest to lower both shoulders so that they would lie perpendicularly along both sides of the bed. The arm and the shoulder were left hanging parallel to the trunk to avoid any artifact from the shoulder blades. To get a good view, we adjusted the C-arm fluoroscope for each affected VB.

The trocar needle was first introduced into the plane between the proximal rib and transverse process at the superior lateral pedicular wall. It was then advanced through the transverse process, costotransverse joint, and rib with a slight twisting motion. The needle was then advanced through the pedicle, and its direction was adjusted depending on the shape of the compressed VB. Once the needle traversed the cortex of the posterior lateral wall of the VB through the lateral pedicular wall, the needle required less pressure to advance into the VB.

Advancement of the needle was controlled in the lateral projection with alternating anteroposterior views. The needle tip was placed in the anterior one-fourth of the VB, and it was close to the spinous process on the anteroposterior view. For severely collapsed vertebrae, a bilateral approach was used, as typically the lateral aspect of the VBs was better presented than the middle. Additionally, in cases of focal kyphosis due to the index fracture, the levels above and below the fracture were also included in the treatment plan. In those cases, it was helpful to first perform the kyphoplasty to treat the adjacent levels and then to treat the index fractured level to achieve optimum contrast and visualization of the fracture on the C-arm screen. In those cases in which radiographic cord compression was seen preoperatively, we used neurophysiological monitoring during surgery. We used MEP and SSEP monitoring before, during, and after balloon inflation. Potentials were also monitored during PMMA injection.

Results

Pain relief and mobility improvement were observed immediately after the operation and maintained until the latest follow-up (mean VAS scores 79 and 30, and mean ODI scores 83 and 33, pre- and postoperatively, respectively; $p < 0.001$) (Table 1). We did not notice any differences in outcome (VAS or ODI) in patients with different tumor histologies, but the numbers of patients in the subgroups were too small to allow any statistical comparison.

The mean kyphotic angle was 25.03° before surgery and 22.65° in the early postoperative period ($p > 0.3$). At latest follow-up, the mean kyphotic angle did not differ significantly from previous measurements (26.3°, $p > 0.1$).

The volume of the PMMA injected per VB varied from 1.5 to 4.5 ml (mean 3 ml). There were no apparent clinical complications directly related to injection of the PMMA. Extravasation of cement (into the intradiscal space) occurred in 3 (10%) of 30 treated VBs and led to termination of the injection. In 5 patients there was preoperative evidence of radiographic cord compression, but the patients were neurologically intact. These patients received similar treatment, with the addition of intraoperative neurophysiological monitoring. None of the patients

TABLE 1: Summary of mean pain and functional capacity scores*

Time of Exam	VAS Score	p Value	ODI Score	p Value
preop	79 ± 12.9		83 ± 12.4	
1st day postop	37 ± 9.9	<0.001	40 ± 15.1	<0.001
3 mos	22 ± 8.9	<0.001	30 ± 6.7	<0.001
6 mos	22 ± 6.9	<0.001	30 ± 10.3	<0.001
12 mos	30 ± 8.2	<0.001	33 ± 7.4	<0.001

* Mean values are presented ± SD. The p values refer to comparison with preoperative scores.

exhibited MEP/SSEP changes during the procedure. All patients remained neurologically intact.

Overall, there were no clinically significant side effects associated with the extrapedicular approach. No neurological deficits or lung-related complications (pneumo- or hemothorax) were reported in any patients. No patients experienced an adjacent-level fracture. Four patients were discharged home on the same day, and 10 patients were discharged within 24 hours (Figs. 1–3).

Discussion

Patients with metastatic spinal disease suffer significant morbidity due to vertebral compression fractures that cause severe pain and affect their QOL. Balloon kyphoplasty in cases of metastatic spinal fracture improves QOL and function by markedly decreasing back pain and reducing intake of pain medications.[1,14,17,18,26,28]

Balloon kyphoplasty is not approved or recommended by the manufacturer (Medtronic, Inc.) for use in the upper thoracic spine. In this study we reviewed data obtained in 14 patients with upper thoracic (T1–5) metastatic neoplasms. All patients were successfully treated with balloon kyphoplasty, and the follow-up period exceeded 12 months.

The mean transverse diameter of the pedicle at the T-1 VB was 6.4 mm in women and 7.3 mm in men. At T-3, however, the mean diameter was 3.4 mm in women and 3.9 mm in men.[21]

The upper thoracic vertebrae have short and narrow pedicles shaped like a heart (back to front), which allows a trocar inserted extrapedicularly to be placed in the anterior part of the VB and in the midline. A transpedicular approach can be hazardous, and even a small amount of cement leakage can cause serious neurological complications because the spinal canal is small.[7,10–12] Limitations include an inadequate pedicle size and lateral angulation of the pedicle with respect to the VB. In thoracic VBs at T-8 and above, pedicles are narrow and laterally directed as previously reported.[21]

Kallmes et al.[11] reported their experience with middle and upper thoracic vertebroplasty via a transpedicular approach. In these cases the final position of the needle was more likely to be in the lateral part of the VB rather than the midline or the anterior part. An appropriate volume of cement cannot be injected due to the lateral placement of the needle.

There is no definitive clinical evidence supporting the

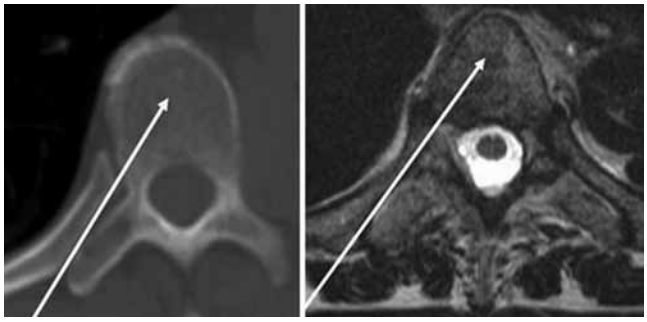

Fig. 1. Axial CT scan **(A)** and axial T2-weighted MR image **(B)** showing the extrapedicular trajectory *(arrow)*.

effectiveness of the extrapedicular approach for upper thoracic vertebral compression fractures. Han et al.[7] reported their experience with the extrapedicular approach for the middle and upper thoracic spine; they commented that the final position of the needle was in the midline and thus they succeeded in injecting a higher volume of cement.

In our experience with the extrapedicular approach, there is a low risk of pedicle fracture because the needle is advanced only through the lateral side of the pedicle. This allows the needle to reach the midline of the VB and sometimes across the midline. The needle passes through the costotransverse joint, rib head, and lateral margin of the pedicle. The chest cavity is protected by the head of the rib. Potential complications of the extrapedicular approach include entering the pulmonary cavity or causing rib fractures.[9,20,21]

In our series, clinically evident myelopathy (but not radiographic cord compression alone) was a contraindication to the operation. Other authorities also do not consider a retropulsed fracture/canal involvement to be a contraindication.[8,23,24] Although the procedure is riskier in those cases, there are some ways to avoid complications; these include use of the following: 1) neuromonitoring (MEPs/SSEPs), 2) more anterior direction of the trocar, and 3) local anesthesia (although in our practice and especially in multilevel kyphoplasty procedures, we opt for general anesthesia). On the other hand, some surgeons would have probably chosen open procedures in some of our cases. However, open surgery in patients with metastatic cancer may be associated with significant morbidity. In general we considered overt instability, myelopathy, and intractable pain after kyphoplasty/radiotherapy or potentially curative cases (for example, in cases involving a solitary renal metastatic neoplasm) as indications for open procedures.[25,27] Patient factors should always be taken into account in the decision-making process (ECOG [Eastern Cooperative Oncology Group] Performance Status, Karnofsky Performance Scale Score, life expectancy). Radiotherapy is also a well-established treatment in patients with metastatic disease. If no cord compression exists according to the recommendations of the spinal oncology team, conventional radiotherapy suffices for local tumor control, particularly for radiosensitive histological types (lymphoma, myeloma, and seminoma).[6,22] In the setting of oligometastatic disease and/or radioresistant histology (even in low-grade cord compression), newer technologies like radiosurgery and intensity-modulated radiation therapy as a single-fraction

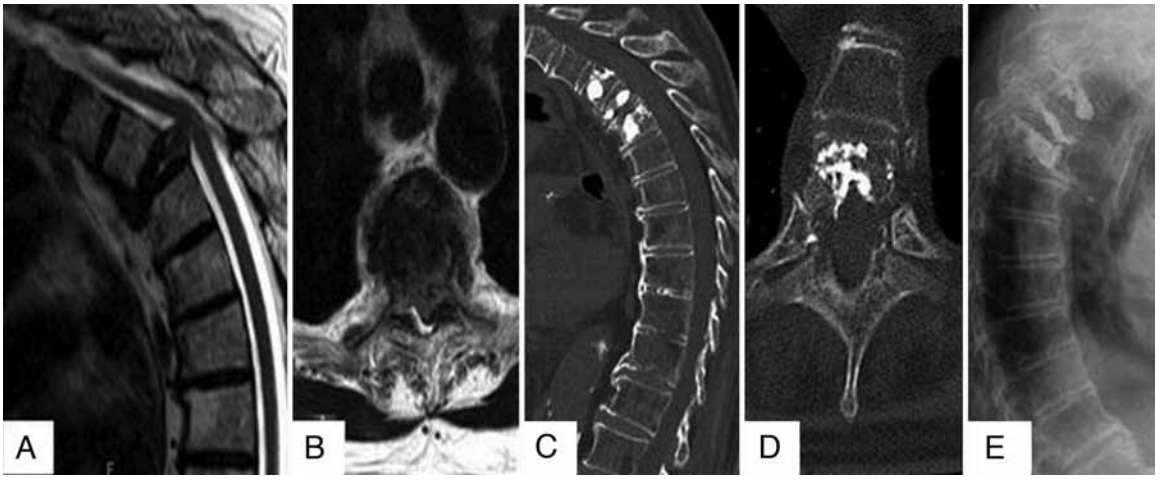

Fig. 2. Illustrative case of an 82-year-old patient with unknown primary cancer, who sustained a T-4 compression fracture with significant kyphotic angulation, cord compression, and severe pain. **A and B:** Sagittal and axial T2-weighted MR images of thoracic spine showing T-4 compression fracture with kyphotic deformity and cord compression at this level. **C:** Sagittal CT scan showing PMMA injection at T-3, T-4, and T-5, with no leakage. **D:** Axial CT scan demonstrating unilateral injection of the pedicle and cement contained in body. **E:** Lateral plain radiograph showing kyphoplasty at T3–5.

treatment are gaining popularity;[2,6] intensity-modulated radiation therapy provides better local control and more durable response while sparing normal tissues from unnecessary irradiation,[6] and in many centers there is a trend to replace conventional radiotherapy. Radiotherapy is known for the detrimental effects to the bone[15] and for further weakening the VB, resulting in a 39% risk of subsequent fractures.[19] Therefore further stabilization may be needed, which can be achieved with kyphoplasty, either before or after radiotherapy. Gerszten et al.[5] reported favorable results in their series of combined kyphoplasty and adjuvant radiosurgery. Overall, since this is a rapidly evolving area, much controversy exists, and neither the therapeutic modality nor their sequence has been well established, with the choice frequently being driven by personal preferences rather than evidence-based data.

There are certain limitations to our study, as it is a retrospective study with no control group and therefore the level of recommendation is low. However, this is a series from a single surgeon (F.D.V.) in a uniform patient population, and we believe that useful conclusions can be drawn. Balloon kyphoplasty was associated with a trend toward improvement of kyphotic angle that lasted for a few months after surgery and returned to the preoperative level after 1 year, which can be explained by the natural history of the disease and continuation of vertebral deformity over time. With regard to pain and functional outcome, the improvement was maintained until the latest follow-up. Pflugmacher et al.[17] reported the same results of improvement in pain and functional outcome, as well as restoration of vertebral height, in patients with metastatic spinal disease. Depending on a patient's medical condition and the angulation of the VB, we performed bilateral or unilateral cement injection. With regard to the diameter of the needle, we agree with Kallmes et al.[11] and Han et al.[7] that a larger diameter makes injection of ce-

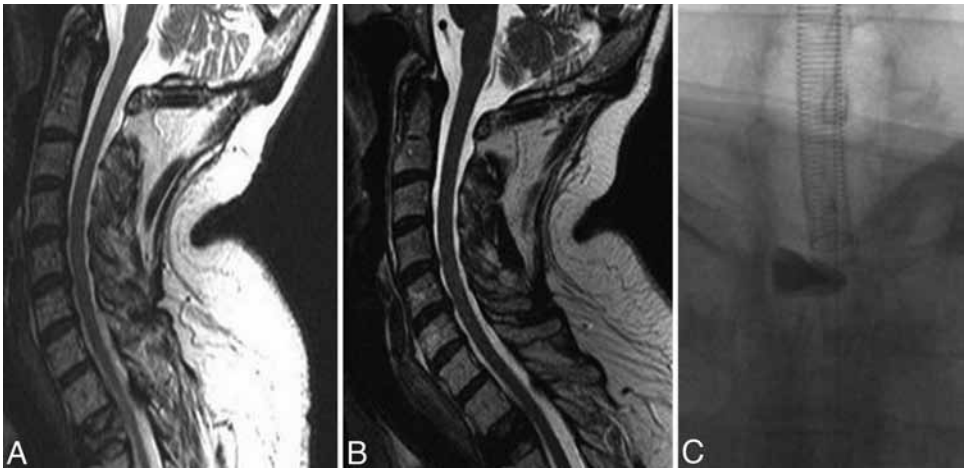

Fig. 3. Illustrative case of a 57-year-old patient with myeloma and T-2 compression fracture. **A:** Axial T2-weighted MR image of the thoracic spine demonstrating a T-2 compression fracture without kyphosis. **B:** Postoperative T2-weighted MR image showing T-2 after cement injection. **C:** Anteroposterior plain radiograph revealing unilateral kyphoplasty of T-2 from the right side.

ment safer and easier. We used a smaller diameter needle only when the remaining height of the compressed VB was less than the outer diameter of the needle.

Conclusions

Balloon kyphoplasty via an extrapedicular approach to the upper thoracic spine is an efficient and safe minimally invasive procedure that provides immediate and long-term pain relief, improvement in functional ability, and prevents further kyphotic deformity. It is technically challenging with a potential for serious complications. With a fundamental knowledge of anatomy, as well as excellent ability to interpret fluoroscopy images, balloon kyphoplasty is feasible and safe in the upper thoracic spine.

Disclosure

Dr. Vrionis is a consultant for Medtronic, and reports that no funding was received for the execution of this study.

Author contributions to the study and manuscript preparation include the following. Conception and design: Vrionis, Eleraky. Acquisition of data: Eleraky. Analysis and interpretation of data: Vrionis, Eleraky, Papanastasiou, Baaj, Tran. Drafting the article: Vrionis, Eleraky, Papanastasiou, Setzer, Tran. Critically revising the article: Vrionis, Papanastasiou, Setzer, Baaj. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Papanastasiou. Administrative/technical/material support: Vrionis. Study supervision: Vrionis.

References

1. Alvarez L, Pérez-Higueras A, Quiñones D, Calvo E, Rossi RE: Vertebroplasty in the treatment of vertebral tumors: postprocedural outcome and quality of life. **Eur Spine J 12:**356–360, 2003
2. Bilsky MH, Laufer I, Burch S: Shifting paradigms in the treatment of metastatic spine disease. **Spine 34 (22 Suppl):**S101–S107, 2009
3. Cheung G, Chow E, Holden L, Vidmar M, Danjoux C, Yee AJ, et al: Percutaneous vertebroplasty in patients with intractable pain from osteoporotic or metastatic fractures: a prospective study using quality-of-life assessment. **Can Assoc Radiol J 57:**13–21, 2006
4. Gaitanis IN, Hadjipavlou AG, Katonis PG, Tzermiadianos MN, Pasku DS, Patwardhan AG: Balloon kyphoplasty for the treatment of pathological vertebral compressive fractures. **Eur Spine J 14:**250–260, 2005
5. Gerszten PC, Germanwala A, Burton SA, Welch WC, Ozhasoglu C, Vogel WJ: Combination kyphoplasty and spinal radiosurgery: a new treatment paradigm for pathological fractures. **Neurosurg Focus 18(3):**e8, 2005
6. Gerszten PC, Mendel E, Yamada Y: Radiotherapy and radiosurgery for metastatic spine disease: what are the options, indications, and outcomes? **Spine 34 (22 Suppl):**S78–S92, 2009
7. Han KR, Kim C, Eun JS, Chung YS: Extrapedicular approach of percutaneous vertebroplasty in the treatment of upper and mid-thoracic vertebral compression fracture. **Acta Radiol 46:** 280–287, 2005
8. Hentschel SJ, Burton AW, Fourney DR, Rhines LD, Mendel E: Percutaneous vertebroplasty and kyphoplasty performed at a cancer center: refuting proposed contraindications. **J Neurosurg Spine 2:**436–440, 2005
9. Hsu W, Sciubba DM, Sasson AD, Khavkin Y, Wolinsky JP, Gailloud P, et al: Intraoperative localization of thoracic spine level with preoperative percutaneous placement of intravertebral polymethylmethacrylate. **J Spinal Disord Tech 21:**72–75, 2008
10. Hulme PA, Krebs J, Ferguson SJ, Berlemann U: Vertebroplasty and kyphoplasty: a systematic review of 69 clinical studies. **Spine 31:**1983–2001, 2006
11. Kallmes DF, Schweickert PA, Marx WF, Jensen ME: Vertebroplasty in the mid- and upper thoracic spine. **AJNR Am J Neuroradiol 23:**1117–1120, 2002
12. Kim HS, Kim SW, Ju CI: Balloon kyphoplasty through extrapedicular approach in the treatment of middle thoracic osteoporotic compression fracture: T5-T8 level. **J Korean Neurosurg Soc 42:**363–366, 2007
13. Masala S, Anselmetti GC, Marcia S, Massari F, Manca A, Simonetti G: Percutaneous vertebroplasty in multiple myeloma vertebral involvement. **J Spinal Disord Tech 21:**344–348, 2008
14. Masala S, Fiori R, Massari F, Simonetti G: Kyphoplasty: indications, contraindications and technique. **Radiol Med (Torino) 110:**97–105, 2005
15. Pelker RR, Friedlaender GE, Panjabi MM, Kapp D, Doganis A: Radiation-induced alterations of fracture healing biomechanics. **J Orthop Res 2:**90–96, 1984
16. Pflugmacher R, Beth P, Schroeder RJ, Schaser KD, Melcher I: Balloon kyphoplasty for the treatment of pathological fractures in the thoracic and lumbar spine caused by metastasis: one-year follow-up. **Acta Radiol 48:**89–95, 2007
17. Pflugmacher R, Kandziora F, Schroeder RJ, Melcher I, Haas NP, Klostermann CK: Percutaneous balloon kyphoplasty in the treatment of pathological vertebral body fracture and deformity in multiple myeloma: a one-year follow-up. **Acta Radiol 47:**369–376, 2006
18. Pflugmacher R, Taylor R, Agarwal A, Melcher I, Disch A, Haas NP, et al: Balloon kyphoplasty in the treatment of metastatic disease of the spine: a 2-year prospective evaluation. **Eur Spine J 17:**1042–1048, 2008
19. Rose PS, Laufer I, Boland PJ, Hanover A, Bilsky MH, Yamada J, et al: Risk of fracture after single fraction image-guided intensity-modulated radiation therapy to spinal metastases. **J Clin Oncol 27:**5075–5079, 2009
20. Ryu KS, Park CK, Kim MK, Kim DH: Single balloon kyphoplasty using far-lateral extrapedicular approach: technical note and preliminary results. **J Spinal Disord Tech 20:**392–398, 2007
21. Seong JY, Kim JS, Jung B, Lee SH, Kang HY: CT-guided percutaneous vertebroplasty in the treatment of an upper thoracic compression fracture. **Korean J Radiol 10:**185–189, 2009
22. Sheehan JP, Shaffrey CI, Schlesinger D, Williams BJ, Arlet V, Larner J: Radiosurgery in the treatment of spinal metastases: tumor control, survival, and quality of life after helical tomotherapy. **Neurosurgery 65:**1052–1062, 2009
23. Stoffel M, Wolf I, Ringel F, Stüer C, Urbach H, Meyer B: Treatment of painful osteoporotic compression and burst fractures using kyphoplasty: a prospective observational design. **J Neurosurg Spine 6:**313–319, 2007
24. Sun H, Nemecek AN: Optimal management of malignant epidural spinal cord compression. **Emerg Med Clin North Am 27:**195–208, 2009
25. Sundaresan N, Steinberger AA, Moore F, Sachdev VP, Krol G, Hough L, et al: Indications and results of combined anterior-posterior approaches for spine tumor surgery. **J Neurosurg 85:**438–446, 1996
26. Tseng YY, Lo YL, Chen LH, Lai PL, Yang ST: Percutaneous polymethylmethacrylate vertebroplasty in the treatment of pain induced by metastatic spine tumor. **Surg Neurol 70 Suppl 1:**78–84, 2008
27. Vrionis FD, Small J: Surgical management of metastatic spinal neoplasms. **Neurosurg Focus 15(5):**E12, 2003
28. Yamada K, Matsumoto Y, Kita M, Yamamoto K, Kobayashi T, Takanaka T: Long-term pain relief effects in four patients undergoing percutaneous vertebroplasty for metastatic vertebral tumor. **J Anesth 18:**292–295, 2004

Manuscript submitted November 10, 2009.
Accepted November 17, 2010.
Please include this information when citing this paper: published online January 21, 2011; DOI: 10.3171/2010.11.SPINE09909.

Address correspondence to: Frank D. Vrionis, M.D., Ph.D., Department of Neurooncology, H. Lee Moffitt Cancer Center and Research Institute, 12902 Magnolia Drive, Tampa, Florida 33612. email: frank.vrionis@moffitt.org.