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Retrospective Study

Comparison Between Radiofrequency Targeted Vertebral Augmentation and Balloon Kyphoplasty in the Treatment of Vertebral Compression Fractures: Addressing Factors that Affect Cement Extravasation and Distribution

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Background: Both vertebroplasty and balloon kyphoplasty have been described for treatment of vertebral compression fractures. Vertebroplasty is known for its high leakage rate compared with balloon kyphoplasty. In vitro studies have shown that high-viscosity cements significantly decrease the incidence of cement leakage and increase the predictability of cement fill in cancellous bonelike substrates compared with low-viscosity cements.

Objective: This study compares the incidence and pattern of cement leakage in cases treated with standard balloon kyphoplasty (BKP) and a novel vertebral augmentation procedure, radiofrequency targeted vertebral augmentation (RF-TVA).

Study Design: Retrospective evaluation of postoperative radiographs.

Setting: Single center inpatient and outpatient population.

Methods: Two methods of vertebral augmentation were utilized. Conventional bipedicular BKP and RF-TVA, a novel unipedicular technique which uses a navigational osteotome to create targeted, bone sparing cavities and RF energy to deliver an ultra-high viscosity cement at a consistent rate via a remote controlled, automated hydraulic delivery system. Postoperative radiographs of patients treated with the 2 techniques were critically analyzed for the incidence and location of cement leakage. Eighty consecutive patients with 106 treated levels were included. Thirty-five patients with 49 levels in the BKP and 45 patients with 57 levels in RF-TVA group were evaluated.

Results: Leakages less than 1-2 mm were not reported since they may not represent any clinical significance. In the BKP group, 6 leakages (12%) were reported (3 discal, 2 venous, one paravaertebral, and no epidural). In the RF-TVA group, a total of 3 leakages (5%) were reported, (one discal, 2 venous, no paravaertebral or epidural). Using contingency analysis for leakage per level, there was a statistical difference for leakage between RF-TVA and standard BKP, $P < 0.01$.

Limitations: Retrospective study, single center.

Conclusions: The RF-TVA technique may provide an approximately 50% reduction in leakage rate when compared to standard BKP. This may be related to the combination of controlled delivery of radiofrequency activated (high viscosity) cement at a fixed, low rate of delivery into site-specific channels created using a navigational osteotome. Additionally, based on the unipedicular access and remotely controlled cement delivery RF-TVA may decrease procedural invasiveness and physician radiation exposure, respectively.

Institutional Review: This study was approved by the Institutional Review Board.

Key words: Balloon kyphoplasty, radiofrequency targeted vertebral augmentation, compression fractures, cement leakage

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Both vertebroplasty (VP) and balloon kyphoplasty (BKP) have been described in treatment of vertebral compression fractures (VCFs). Galibert et al (1) first introduced VP in the early eighties in which polymethylmethacrylate (PMMA) cement was injected into a C2 hemangioma. The technique eventually advanced over the years with development of different needles and injection devices. The concept of using balloon tamps in BKP was introduced in the late nineties for purposes of containing low viscosity PMMA cement and achieving height restoration (2). In BKP, a balloon is first inflated to attempt height restoration and create a cavity to permit low-pressure delivery of cement. While height restoration can be achieved during BKP, the relative percent of height restored required to be clinically relevant has yet to be proven. Additionally, height restoration has been reported to occur during VP in acute fractures (3), demonstrating that fracture acuity and bone density are important criteria in determining the degree of height restoration. Cavity creation prior to cement delivery has been shown in meta-analysis studies to result in relatively lower cement leakage rates than VP (4); however, it also can create a barrier for cement to interdigitate. Simply filling the balloon-created void, which can result in the lack of interdigitation of cement into the adjacent native trabecular bone, has been proposed as undesirable and a potential mechanism for long-term failure and re-fracture (5).

Cement leakage, particularly into the epidural space and venous system, remains a major source of potential complication for both procedures (6). Many authors (7) hypothesized that cement viscosity and injection volume were the critical factors in controlling cement leakage. Baroud et al (8) verified this hypothesis in vitro, demonstrating cement leakage in a fractured vertebral body model was reduced from 50% to 10% of the total injected cement when the viscosity of the material was increased from low to medium. Leakage ceased completely when the cement reached high viscosity, defined as being comparable to that of dough. A recent study showed that using high viscosity cement in VP might result in a leakage rate similiar to BKP, arguing that large cavity creation may have little value in controlling cement leakage (9).

Recently, a new technique has been introduced for the treatment of vertebral compression fracture called radiofrequency targeted vertebral augmentation (RF-TVA) (10). Before cement injection, a mechanically robust, navigational (steerable), articulating osteotome is introduced into the vertebral body via uni-pedicular access using a transpedicular or parapedicular approach. The osteotome is used to create site and size specific channels inside the cancellous bone, including the contra-lateral side, to optimize cement distribution in the vertebral body while relatively sparing intact native trabecular bone compared to BKP. The cement, which has a long working time (over 40 minutes), is heated just prior to entering the delivery cannula using a radiofrequency source. The heating process results in a rapid and significant increase in cement viscosity to that portion of the cement entering the delivery cannula just prior to delivery. This allows the cement in the syringe to have an extended working time while the cement being delivered to the patient is at a consistently high viscosity. Cement is delivered at a controlled and consistent rate using a remote controlled, automated hydraulic system, which reduces the need to be in close proximity to the imaging equipment and thereby reducing radiation exposure to the operator.

The purpose of this retrospective, comparative study is to test the hypothesis that an innovative method of vertebral augmentation, RF-TVA, which creates preferential channels inside the vertebral body prior to injection of an radiofrequency heated high viscosity cement, at a controlled delivery rate, allows more targeted vertebral augmentation and hence lower leakage rate than conventional BKP.

Methods

Study Design

A single-center retrospective chart and critical post-operative review of radiographic images was performed on a total of 80 patients treated with BKP (KyphX Expander IBT, Kyphon, Sunnyvale, California), or RF-TVA (StabiliT Vertebral Augmentation System, DFINE, San Jose, CA). All patients initially presented with painful collapsed vertebra(e), which had not responded to conventional conservative therapy. Preoperative work-up included magnetic resonance imaging (MRI) and plain radiographs for all patients. Pain on physical examination was concordant with MRI and radiographic findings confirming the source of pain was a VCF (Fig. 1). Institutional review board permission was obtained for this retrospective study.

Surgical Techniques

All patients were placed in a prone position and given conscious sedation in the radiology interventional

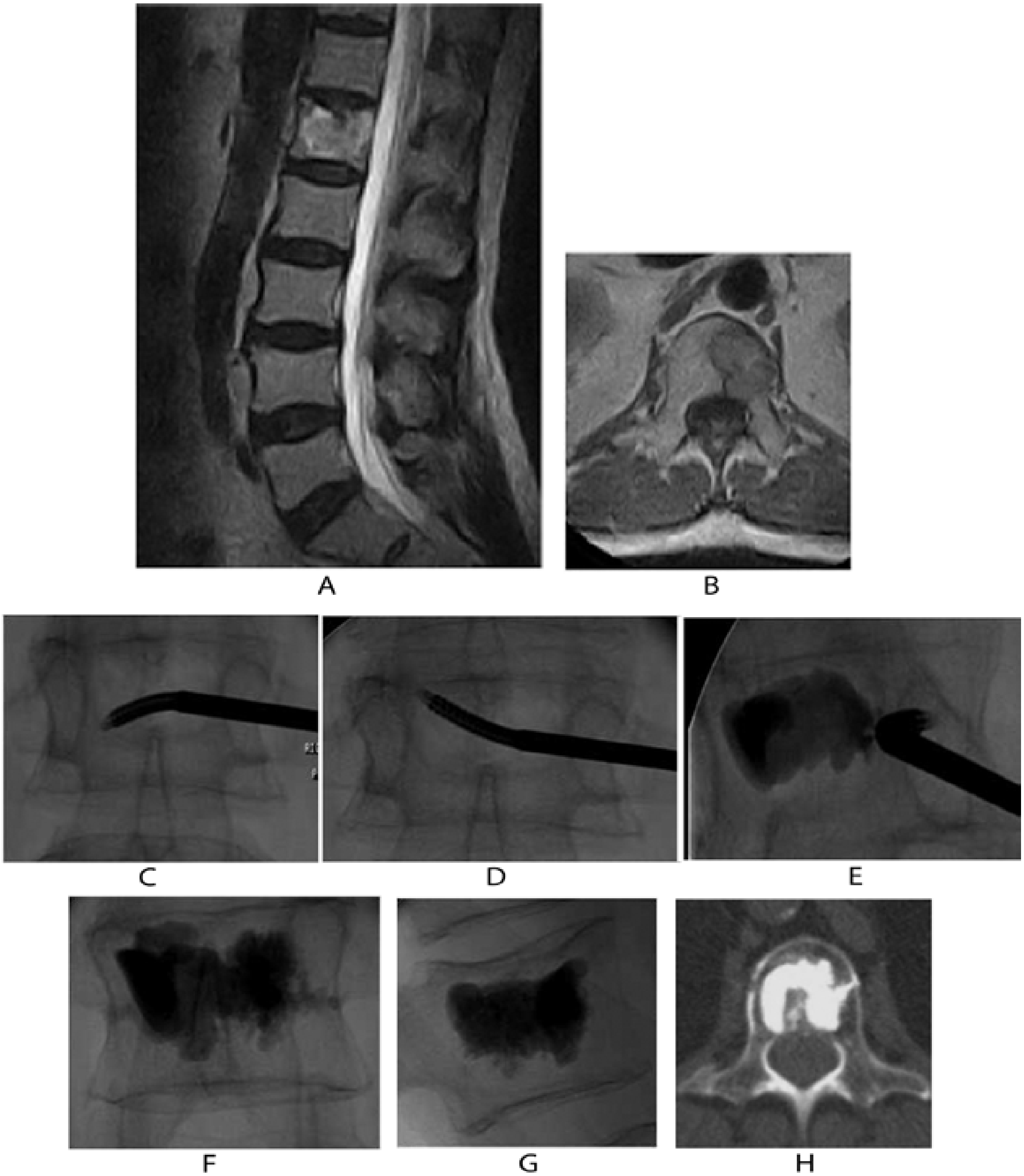

Fig. 1. *75 years old with multiple myeloma with a lytic lesion on L1 vertebral body.*
A is a sagittal T2-weighted image showing high signal intensity lesion on the L1 level. B is an axial T1-weighted image showing a myeloma lesion on the left side of the vertebral body of L1. C and D show different tracts and channels created before cement injection using the StabiliT Vertebral Augmentation System. E shows cement delivered first accumulated in the lytic lesion on the contra lateral side. The navigational ostoeotome is used to create ipsilateral channels. F shows preferential delivery of high viscosity cement to the ipsilateral side with equal cement distribution on both sides of the vertebral body and extensive interdigitation into spared bone adjacent to the osteotome created channel. G is the lateral view after completion of cement delivery. H is CT images of the same level showing equal cement distribution. A tiny leakage can be seen on the left side.

suite. The end point of cement injection for all techniques was the presence of radiologically adequate filling, the start of extravasation, and/or significantly increased pressure during injection. After the procedure, patients were monitored for 2-3 hours post-operatively to ensure full recovery and were discharged the same day. All cases were performed in an advanced interventional radiology suite using a single or biplane Philips unit. Cement injection was performed under live fluoroscopic monitoring to evaluate for any possible venous emboli. At the conclusion of the procedure dedicated antro-posterior and lateral images were obtained that included the levels above and below the treated vertebra. Those high resolution images were used to assess the leakage.

Balloon Kyphoplasty (BKP)

A bipedicular approach was used in 88% (43/49) of the levels. The needle (a 13-gauge beveled bone marrow harvesting needle) placement was performed under fluoroscopic guidance. The needle was exchanged over a K-wire to a standard 9-gauge working cannula (KyphX Expander, Medtronic). Through the working cannula, a drill (to create a tract when necessary) or the balloon was introduced into the center of the vertebral body. Either a 10- or 15-mm balloon was used. Bone cement (Dough-Type; Zimmer, Warsaw, IN) mixed with Biotrace sterile barium sulfate (Bryan, Woburn, MA) was used for augmentation and delivered by hand with the standard BKP bone-filler devices. An average of 3.5 mL was injected in levels treated with BKP.

Radiofrequency Targeted Vertebral Augmentation (RF-TVA).

A bi-pedicular approach was only required in 12% (7/57) of RF-TVA treated levels using the StabiliT Vertebral Augmentation System (DFINE Inc, San Jose, CA). A standard 9-gauge working cannula was first used to access the posterior part of the vertebral body. An articulating bone osteotome was then used to access remote regions of the vertebral body to create targeted channels throughout the vertebral body and across the midline to areas determined during pre- and intra-operative assessment requiring augmentation. Routinely, 3 paths are performed inside the vertebral body along the superior, middle, and inferior portion of the compressed vertebra. When targeted augmentation is targeted beneath a compressed endplate, the osteotome is directed under the endplate to facilitate cement flow in that direction. Radiofrequency activated high viscosity cement was then delivered at a constant rate of 1.3 mL per minute using a hand switch on a 10-foot cable. The frequency of the radiofrequency energy delivered is 480 KHz. An average of 3 mL was injected in levels treated with RF-TVA.

Table 1. *Demographics, leakage occurrence, and location in the 2 minimally invasive VCF procedures evaluated.*

	BKP	RF-TVA
Number of cases	35	37
Number of levels treated	49	57
Male/Female ratio	7/28	14/31
Average age/years	80.8	74
Osteoporotic/Malignant VCF	34/2	29/8
Total number of levels with leakages	6	3

Data Analysis

A single reviewer, a senior neuroradiologist, blinded to the augmentation procedure, meticulously reviewed post-operative posterior-anterior and lateral radiographs for all patients. When leakage was observed in either view, the location was recorded. Leakages less than 1-2 mm were not reported since they are of questionable clinical significance. Leakage was classified by the following locations: 1) disc space, 2) epidural space, 3) paravertebral areas, and 4) peripheral veins. Comparison of leakage rates between the 2 treatment groups was performed by contingency statistical analysis.

Results

A total of 80 (21 men and 59 women) consecutive patients with painful collapsed vertebral bodies that did not respond to conservative non-operative therapy underwent vertebral body augmentation. Levels treated included T5 to L5.

All cases were benign compression fractures except 10 cases that were due to different malignant etiology (2 in the BKP group and 8 in the RF-TVA group). Seventeen cases had more than one level treated, 7 in the BKP group and 10 in the RF-TVA group). RF-TVA had a significantly lower leakage rate per level than BKP, $P < 0.01$ (Table 1).

Discussion

These data show that treatment of VCF with RF-TVA can reduce the frequency of cement leakage by approximately 50% compared to standard BKP in a similar patient population. Both techniques resulted in a symptomatic cement leakage. The lower leakage rate with RF-TVA appears multifactorial and suggests the StabiliT Vertebral Augmentation System enables the operator to address the 3 factors described by Lador et al (11) that influence cement leakage as well as cement flow within a vertebral body:

1. bone morphology and fracture patterns
2. cement properties (viscosity), and
3. injection method (speed, pressure, needle placement).

Bone- and fracture-related parameters may play a dominant role in explaining variations between patients. Because of the wide range of indications for vertebral augmentation, the procedure is applied to a wide range of bone densities and porosities and a wide range of fracture morphologies (12). During RF-TVA, use of the navigational midline osteotome, specifically designed to permit bone-sparing channels, resulted in targeted flow of the RF activated high viscosity cement. After preferentially filling the osteotome-created channels, the cement infiltrated the large surface area along the channels permitting consistent interdigitation of cement into the adjacent trabecular bone. This occurred both in regions with relatively dense trabecular bone as well as more severely compromised regions with thin, sparsely spaced trabeculae. In combination, the creation of preferential paths and filling with high viscosity cement that could be stopped and started over extended periods of time, due to the extended working time of the cement prior to radiofrequency heating, addressed the natural tendency for cement to follow the path of least resistance and leak prior to adequate filling of the fractured vertebra.

With respect to cement properties, it has been suggested that the cement should spread through the vertebral body in a controlled manner that appears fluoroscopically as a "uniformly expanding cloud" (8). The viscosity of the cement, which is a measure of the resistance of a fluid to deformation by stress and the resistance to flow, correlates significantly with its leakage potential. The viscosity is represented in the international system of units by the Pascal second. The Pascal second expresses the ratio between the pressure applied to a fluid and the induced shear rate. High-viscosity material means that the fluid is thicker and more resistant to flow, thus requiring greater pressure to be applied to produce a given shear rate. Baroud et al (8) demonstrated that cements with higher viscosity spread more uniformly than cements with lower viscosity, thus, significantly reducing the risk of leakage. Cement viscosity is directly related to the degree to which the cement has polymerized, which is a time and temperature dependant reaction. Conventional cements routinely pass through a high viscosity stage as it polymerizes (hardens) but is only usable for a relatively short period of time before becoming too viscous to deliver. The StabiliT Vertebral Augmentation System allows delivery of consistently high viscosity cement for over 30 minutes by modulating the viscosity of the cement using radiofrequency energy. Application of variable amounts of radiofrequency energy to the cement just prior to the cement entering the delivery needle results in a consistently ultra-high viscosity cement being delivered inside the vertebral body, despite an extended working time prior to being exposed to radiofrequency.

Injection methods (volume, speed, pressure, needle placement) are the third factor that affects leakage. The StabiliT Vertebral Augmentation System uses an automated hydraulic controller that delivers cement at a controlled rate of 1.3 mL per minute. The combination of an optimized delivery rate and preferential flow of cement through the osteotome created channels may help decrease the intra-vertebral pressure during cement delivery that can result in uncontrolled extravasation.

Support of the theoretical benefit of creating targeted channels prior to cement delivery is provided by Oberkircher et al (13) and Dalton et al (14). In those cadaver studies, interdigitation between trabecular bone and cement was observed to be better in RF-TVA procedures that create smaller targeted channels as opposed to procedures in which balloon inflation resulted in large cavities lined with crushed bone.

Stress shielding is a well-known effect observed in bone adjacent to knee and hip prostheses, in which the majority of the physiological loads are carried by the stiffer prosthetic material. In the case of minimally invasive treatment of VCFs, large cement boluses are required to fill the cavities created by balloon expansion and have been described by Dabirrahmani et al (150 to create what is known as a material modulus mismatch, which can relieve the surrounding bone of load. According to Wolff's law (16), this off-loading can result in bone resorption by stress shielding and ultimately osteolysis. Analogously, bone in the spine should also behave in similar fashion. Stress shielding is especially detrimental in cases of severe osteoporosis (5). Because of this phenomenon the authors believe that a VCF procedure that destroys bone to create large cavities should be used with caution in patients with severe osteoporosis or osteonecrosis. In addition to potential for improved interdigitation, interest and availability of systems that are capable of targeted cavity creation as opposed to balloon devices is increasing as they permit a unipedicular access to the vertebral body thus decreasing procedural invasiveness.

Limitations of this study include the fact that it was conducted retrospectively, and as a result, despite consecutive patients being evaluated, had no clear methodology to ensure unbiased randomization of the 2 groups. The image review process was also performed with a single reviewer, which could limit the sensitivity of the results. Of interest Is that the RF-TVA group did include more malignant compression fractures which have been reported to have higher incidence of leakage than benign osteoporotic fractures. In addition, this study was conducted at one site and may, therefore, not reflect possible inter-operator variability, typical for surgical devices. Even with the relatively smaller number of cases in this study, the comparative improvements mirror those of Pflugmacher et al (17) who recently reported significantly lower leakage rates in RF-TVA than BKP procedures in a large 228 patient clinical study where they reported a key difference in cement leakage in favor of RF-TVA of 6.1% versus 27.8% ($P < 0.0001$). Despite the above-mentioned limitations, observational studies are the mainstay of the literature for initial reports and for complications in general. Considering that there have been few studies in this area, this retrospective but critical radiographic evaluation, provides important information for current clinical use of an innovative approach to minimally invasive treatment of VCFs and future controlled prospective studies.

Conclusion

This study showed that the combination of targeted bone-sparing channel creation coupled with delivery of high viscosity cement in a controlled consistent rate address the criteria proposed by Lador et al (11) to reduce extravasation and result in a significantly lower rate of cement leakage and optimized cement distribution during treatment of VCFs.

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