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Anatomic Technical Report

Sacral Vertebral Augmentation: Confirmation of Fluoroscopic Landmarks by Open Dissection

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Sacral insufficiency fractures are a more commonly recognized cause of spine pain among osteoporotic patients, and are now treatable by sacroplasty using percutaneous instillation of PMMA cement. Sacroplasty may be performed using only fluoroscopic landmarks; however, the bony anatomy of the sacrum is complex and the cement deposition based on these landmarks has not been specifically confirmed. In this report we determined the precise fluoroscopic landmarks for cannula placement in a specially prepared excised sacral cadaveric specimen with metal surface markers. The cannulas were placed using the usual dorsal approach, and where the tip was visually seen to breach the cortical surface, fluoroscopic images were obtained and the boundaries of the sacrum were carefully determined. A fluoroscopic cortical "breach" area emerged where a cannula tip would likely be outside the cortical boundaries of the sacrum.

With simple sacral vertebroplasty there is no direct control of cement deposition after the PMMA leaves the tip of the cannula. The use of vertebral augmentation devices may be of use to help control cement delivery in performing sacroplasty. We evaluated 2 such devices in cadaver specimens to determine their suitability in performing a sacral vertebral augmentation.

Using these same landmarks, a sacral balloon Kyphoplasty was performed and the cadaveric specimen was subsequently bivalved to visually confirm the deposition of cement. On direct inspection the PMMA cement was found to be confined within the sacral cortical boundaries and there was no extravasation near or into the sacral foramen.

Based on these fluoroscopic landmarks, the Arcuplasty device was tested in an intact cadaver to determine the optimal cannula placement and locations for creating osteotomies within the sacral trabecular bone prior to PMMA cement deposition. The cement deposition was observed to remain closely confined to the areas where the osteotomies were performed. In the balloon Kyphoplasty specimen the cement deposition was visually confirmed to be confined within the cortical boundaries by open dissection, and both devices have been found successful in creating a more controlled deposition of PMMA cement for performing sacral vertebral augmentation under fluoroscopic imaging.

Key words: Sacroplasty, vertebroplasty vertebral augmentation, kyphoplasty, sacral insufficiency fractures, osteoporosis.

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Sacral insufficiency fractures are now a more frequently recognized cause of severe axial lumbosacral pain that has historically been largely under diagnosed (1). These fractures typically occur in patients with the same underlying conditions that lead to compression fractures of the vertebral bodies, such as primary osteoporosis, prolonged steroid administration, primary bone tumors, and metastatic disease (2). Unfortunately, these fractures are not readily visible on standard x-rays and typically require specific imaging to detect. MRI scans obtained with slices through the sacrum may show edema in the sacral body or sacral ala, whereas CT scan may demonstrate cortical disruption to identify a suspected fracture, and they may reveal the overall extent of sacral fracture involvement. Alternatively, imaging by bone scan scintigraphy may yield the diagnostic "Honda sign" with uptake in the sacral ala making up the vertical component of the fracture and the sacral body component forming the crossbar of the Honda sign (3). Even when properly diagnosed, there still remained the problem of no effective treatment to stabilize the fracture. Conservative management typically consists of bed rest and pain medication, which often leads to complications from immobility including DVT, pulmonary embolus, pneumonia, progressive bone demineralization, and even death.

Since the advent of vertebroplasty for the percutaneous delivery of polymethylmethacrylate (PMMA) cement for the treatment of painful vertebral fractures, this technique has recently been successfully applied to the treatment sacral insufficiency fractures (4,5). Due to the relatively complex bony anatomy of the sacrum combined with multiple associated foramina containing sacral nerve roots, the procedure is often performed by CT guided cannula placement followed by PMMA cement injection under fluoroscopic imaging (6,7). Fluoroscopy is important to provide real time assessment of PMMA cement delivery to avoid inadvertent extravasation into 1 or more sacral foramen and potential nerve root injury. The requirement for CT and fluoroscopic imaging modalities makes the procedure time consuming and complex; however, some practitioners have the availability of combination CT/fluoroscopy units that greatly simplifies the procedure.

Many institutions are lacking sophisticated combined CT/fluoroscopy units, so an effective fluoroscopy-only technique would make the procedure more accessible to patients and practitioners. An all-fluoroscopic technique has been previously published by this author, based on sacral anatomic dimension measurements obtained from CT scans combined with available fluoroscopic anatomy (8). The technique has been successful in reliably depositing PMMA cement within the sacral intra-osseous space and avoiding cement extravasation into the sacral foramen. This approach, however, has not been specifically confirmed by post procedure CT scanning or by direct anatomic inspection in post mortem specimens or cadaver specimens to detail the actual deposition of PMMA cement.

To increase the safety and reliability of fluoroscopic imaging in performing sacral vertebroplasty, we utilized direct inspection of sacral cadaveric specimens for determining the precise boundaries based on fluoroscopic landmarks. A cadaveric sacrum was fully excised and metal markers placed over the lateral and ventral surfaces. Cannulas were inserted in the usual fashion and any cortical breach could be visually observed. Fluoroscopic images were then obtained to identify the fluoroscopic landmarks that would be useful to define the boundaries of the sacrum, where the cannula tip would be outside the cortical boundaries. A sacral augmentation was performed with PMMA cement instilled under fluoroscopic imaging. This was followed by open dissection of the specimen to determine where the exact location and deposition of PMMA cement actually occurred. In this fashion, the fluoroscopic landmarks and expected PMMA cement deposition could be directly confirmed, and identify potential unrecognized cement extravasation into undesirable areas that may not be discernable by fluoroscopy alone.

In sacral vertebroplasty there is little control in the direction the cement travels once injected into the sacrum. Ideally, the PMMA material would follow the fracture line to stabilize the sacrum but avoid the neuroforamen and spinal canal. Balloon Kyphoplasty and the Arcuate osteotomy system, Arcuplasty, are designed as vertebral augmentation devices that help control the direction of cement delivery for vertebral fractures. The balloon Kyphoplasty device has been previously described to treat sacral insufficiency fractures using advanced imaging guidance tools with good results (9). The Arcuate system is fairly new and there are no previous published reports on the use of this device in the treatment of sacral insufficiency fractures.

In this study a sacral vertebroplasty was performed using a balloon Kyphoplasty system for cavity creation within the marrow space of the sacrum prior to cement delivery. The sacral specimen was bivalved by osteotomy and the cement deposition was directly inspected. In a separate study using an intact cadaver, the Medtronic Arcuplasty device was tested to create internal osteotomies of the sacral trabecular bone prior to cement delivery. The location of PMMA cement deposition was determined by fluoroscopic landmarks as defined by the previous study, but an open dissection of the cadaver was not performed.

Methods

To better define the fluoroscopic landmarks to accurately perform sacral vertebroplasty, a cadaver specimen was utilized where the entire sacrum was excised and cleansed of adherent muscle or soft tissue. Multiple thin metal markers that would be easily visible under fluoroscopy were positioned over the ventral and lateral surfaces of the specimen (Fig 1). Cannulas were then inserted from the dorsal surface directed from medial to lateral, in the usual fashion for performing sacral vertebroplasty, and advanced until the tip was visually determined to have breached the anterior cortical surface of the sacrum. Once the breach had occurred careful AP and lateral fluoroscopic images were obtained to define the precise boundaries of the sacrum, where the cannula tip could be reliably confined within the intra-osseous compartment of the sacrum (Figs 2-5.)

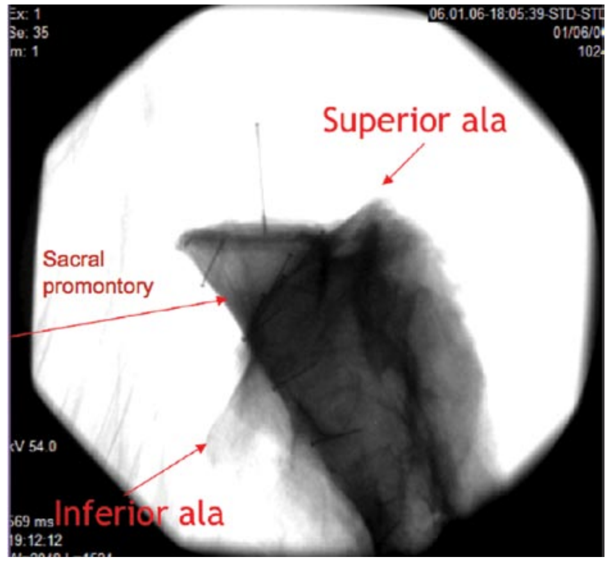

Fig. 1. *Excised sacral specimen with metal markers on the ventral and lateral surfaces.*

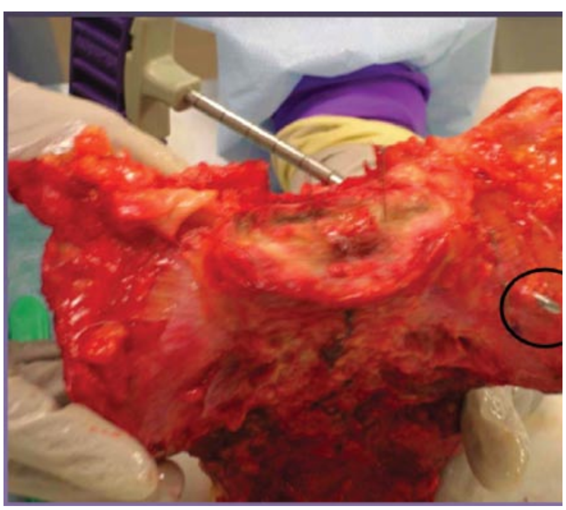

Fig. 2. *Cannula tip breach of anterior sacrum.*

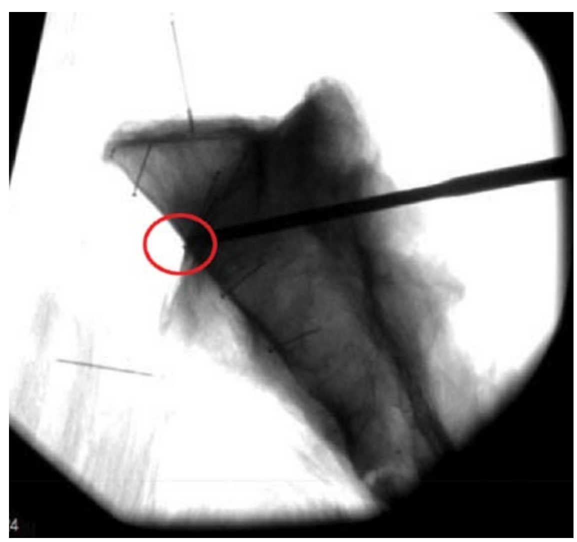

Fig. 3. *Fluoroscopic view of cannula tip breach.*

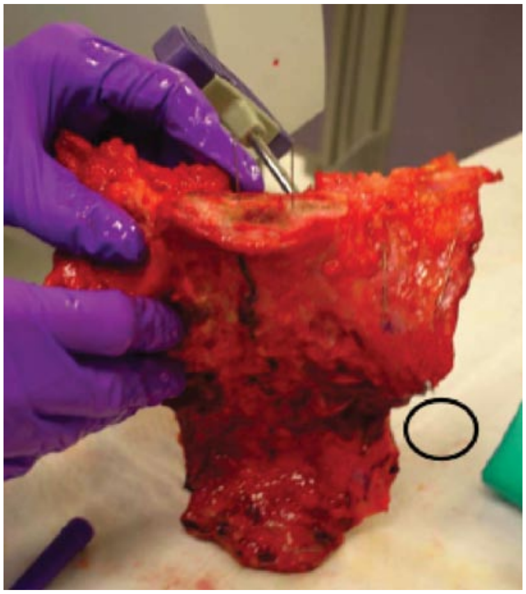

Fig 4. *Cannula tip breach of anterior surface of the inferior ala.*

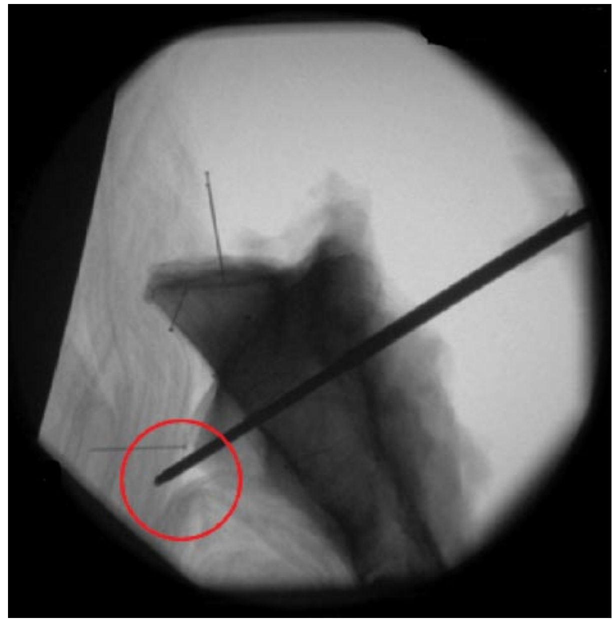

Fig 5. *Fluoroscopic view of the cannula tip breaching the anterior surface of the inferior ala.*

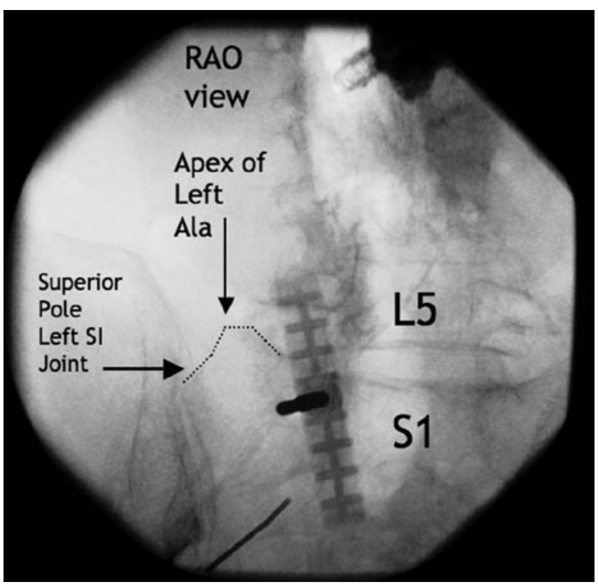

Fig. 6. *Right anterior oblique view of the left SI joint and apex of sacral ala with cannula inserted caudad to the ala and medial to the SI joint.*

Typically, sacral vertebroplasty is performed by first identifying the L5/S1 segment in an AP view on the fluoroscopic image. The superior endplate of S1 is then squared off using a cephalo-caudad tilt, and the C-arm is then rotated obliquely until the superior pole of the sacroiliac joint becomes visible. A cannula is then inserted about 2cm caudad from the superior-most aspect of the sacral ala and 1 – 2 cm medial to the sacro-iliac joint (Fig 6). On the lateral image the cannula trajectory should be adjusted until it is parallel to the slope of the superior endplate of S1. The cannula is then advanced “down the barrel” from medial to lateral into the body of the sacral ala without breaching the ventral surface.

A second cannula may be inserted 2cm caudad and parallel to the first cannula, then advanced in a similar fashion into the body of the lateral sacrum itself, again, without compromising the ventral surface. In some instances, only a single cannula is sufficient to treat the sacral fracture if the fracture is confined to the ala based on pre-operative imaging. If the fracture is more extensive, then 2 cannulas per side are more effective in obtaining cement spread to all the sacral elements involved with the fracture. In the setting of bilateral sacral fractures, the cannula hubs will typically criss-cross, so the cannula insertion must be adjusted to navigate around the hub positions from the cannulas inserted in the opposing side.

By applying fluoroscopic imaging of the metal-marker prepared specimen, the boundaries of the sacrum were successfully well demarcated. Any cannula breach of the cortical surface was readily detected by direct observation of the specimen. Fluoroscopic images obtained subsequent to cannula tip breach accurately defined the fluoroscopic cortical boundaries of the sacral specimen as would be viewed in the actual performance of a sacral vertebroplasty. In this fashion, a well-defined triangular breach area emerged where any stray cannula tip was likely to be outside the prescribed desired boundaries for optimal PMMA cement delivery within the sacrum and ala (Fig 7). The inferior aspect of the sacral ala was noted to extend fairly anterior to the ventral surface of the body of the sacrum itself (Figs. 4, 5). The ventral surface of the lateral sacrum appears as a smooth slope from the superior ala to the inferior ala. On a true lateral image these sloping lines should closely overlap for optimal fluoroscopic positioning. This area provides a fairly large volume of intra-medullary space for safe cannula placement and PMMA cement deposition that is readily visible under typical fluoroscopic imaging in an intact specimen or patient.

Fig. 7. *Triangular breach zone where cannula tip and PMMA cement would be outside of the lateral sacrum.*

Alternatively, the triangular breach area would be the target zone for cannula placement for an S1 body cement deposition. This is the anatomic zone for placement of an S1 pedicle screw during spine fusion surgery. For pain relief from sacral insufficiency fractures the sacral body component is not routinely targeted for cement deposition. The “crossbar” on the “Honda” sign as seen on a bone scintillation scan corresponds to the S1 or S2 body; whereas, the sacral ala corresponds to the “uprights” in the setting of a complete sacral insufficiency fracture. Given the neural elements and spinal canal are located in the central section of the sacrum, there is some risk of trespassing the central canal with cannula placement through the S1 “pedicle” directed medially toward the central body of S1. Many practitioners may find it more suitable to use CT guidance for S1 body cannula placement, depending if the fracture is primarily involving the body of S1, and not the ala and/or lateral sacral elements, i.e., the “uprights” of the “Honda” sign.

With the sacral boundaries now well defined by fluoroscopic landmarks, a separate intact lower torso cadaveric specimen was prepared. In this specimen a sacral Kyphoplasty was performed by placing large bore Kyphoplasty cannulas from the typical dorsal trajectory until the tip was just deep to the dorsal cortical surface based on lateral fluoroscopic images. A channel forming drill bit was inserted through the cannula prior to the insertion of the balloon, with attention to not breach the anterior cortical surface as defined previously by the fluoroscopic boundary criteria. A 15mm balloon was then inserted through each cannula, and inflated until the balloon wall could be seen occupying the intra-osseous compartment of the ala and sacral body to create intramedullary voids (Figs. 8, 9). The balloon pressures were typically below 200 psi throughout the procedure and none of the balloons were compromised or torn during the inflation process. The balloons were then deflated and PMMA cement was then instilled under fluoroscopic imaging in the usual fashion until the voids were adequately filled, and there was no evidence of cement extravasation outside the prescribed cortical boundaries or into the sacral foramen. A total of about 3 to 4 mL of PMMA cement was delivered per side.

After completion of the cement delivery the sacral specimen was dissected free of the surrounding lumbar spine and pelvic structures until it was completely excised from the cadaver. On direct visualization and palpation of the excised sacrum, there was no evidence of PMMA cement extravasation outside

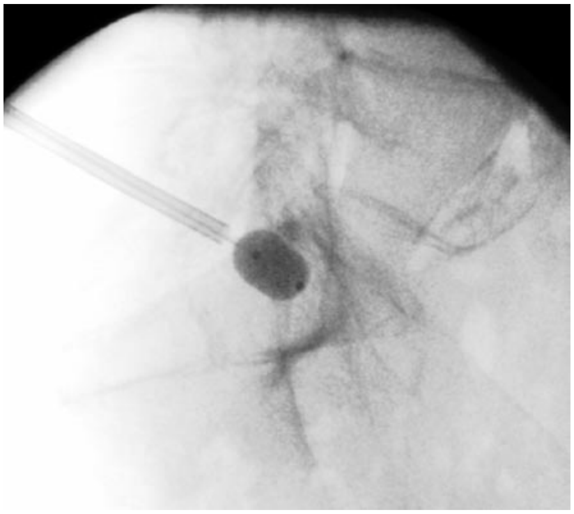

Fig. 8. *Sacral Balloon deployment lateral view.*

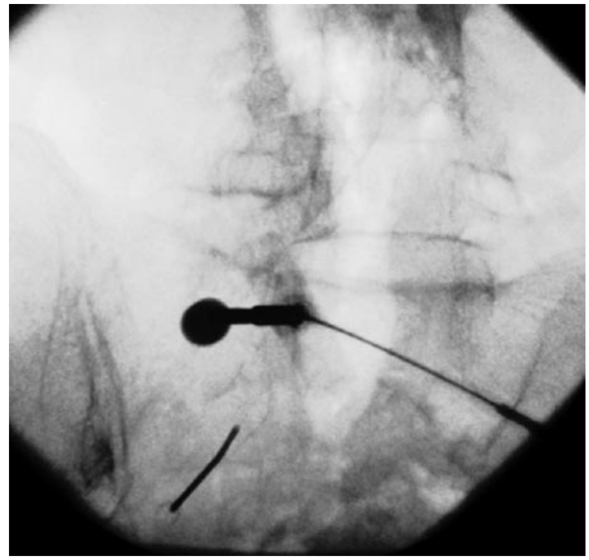

Fig. 9. *Balloon deployment AP view with metal marker over S2 foramen.*

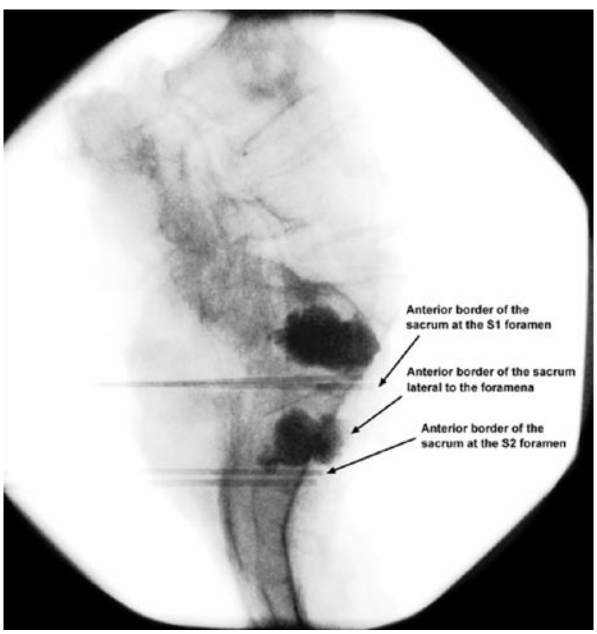

Fig. 10. *Lateral view of cement deposition with metal markers in S1 and S2 foramen.*

the bony confines of the sacral specimen. The sacral neuroforamen were identified by visual inspection and metal marker needles were inserted through each of the S1 and S2 foramen. Lateral fluoroscopic images were obtained of the isolated sacral specimen to identify the cement deposition locations relative to the actual foramen, as defined by the metal needle markers (Fig 10). As is evidenced by direct inspection and fluoroscopic imaging there was no evidence of cement extravasation into either the S1 or S2 neuroforamen. As a final confirmation, osteotomies were performed through the ala and lateral sacral elements where the cement was deposited. On direct inspection, the PMMA cement was confined to the intramedullary space of the lateral sacrum, without leakage into the foramen or outside the confines of the cortical bone. The direct visualization clearly confirmed that the fluoroscopic boundaries were reliable indicators of the actual PMA cement delivery into the sacrum.

A new device has recently become available for vertebral augmentation developed by Medtronic that utilizes a flexible Nitinol-based blade, termed Arcuate XP. The vertebral body is accessed percutaneously by a large bore cannula via the usual transpedicular approach. Once positioned within the vertebral body, the Arcuplasty device in inserted through the access cannula and the Nitinol blade is deployed so as to form a metal arc within the marrow cavity. An internal osteotomy is performed by deploying and rotating the blade within the trabecular bone of the vertebral body. The osteotomy results in a lower resistance path within the vertebral body where cement deposition preferentially occurs, thus allowing for more controlled cement delivery. A sacral Arcuplasty was performed in a cadaver specimen to evaluate the system. The device cannula was inserted in an intact caver specimen in the same trajectory as previously described into the lateral sacral body. After insertion of the cannula the Nitinol blade was deployed in a lateral direction away from the sacral foramina and rotated cephalad and caudad to effect an internal osteotomy of the sacral trabecular bone. PMMA cement was then instilled and was found to preferentially flow to the areas where internal osteotomies were formed, which allowed for more controlled cement deposition. Again, a total of about 3 to 4 mL of cement was delivered per side. There was no evidence of stray cement extravasation by the previously determined sacral fluoroscopic boundaries criteria.

The Arcuplasty device was subsequently used for the treatment of several patients with a sacral insufficiency fractures with excellent control of cement delivery. The intra-operative images are referred to in the following description of the procedure. The cannulas are placed in a similar fashion as a standard sacral vertebroplasty but inserted to a greater depth into the lateral marrow cavity of the sacrum, until the tips were near the anterior sacral border as previously defined by the fluoroscopic boundaries. With the cannula tips well within the lateral sacrum the Nitinol Arcuplasty blade is positioned to deploy in a lateral direction initially. Once deployed the curved blade is rotated in a cephalad direction until it is fully aligned with the saggital plane (Fig 11). While still in the deployed position the blade is then rotated back in the lateral direction and additionally rotated until the blade is facing in a caudal direction, again, parallel to the saggital plane (Figs. 12, 13). This 180-degree rotation results in an internal osteotomy of the trabecular bone within the lateral sacral marrow cavity, thereby forming a path of least resistance that is directed laterally away from the sacral foramen which are located medially relative to

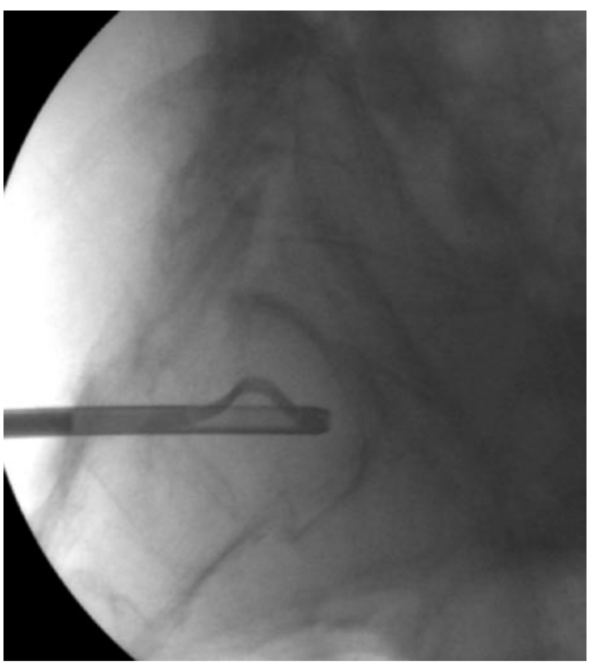

Fig. 11. *Lateral view of cephalad deployment of the Arcuplasty blade forming an internal osteotomy within the lateral ala intramedullary space lateral view.*

Fig. 12. *Caudad deployment of the Arcuplasty blade lateral view.*

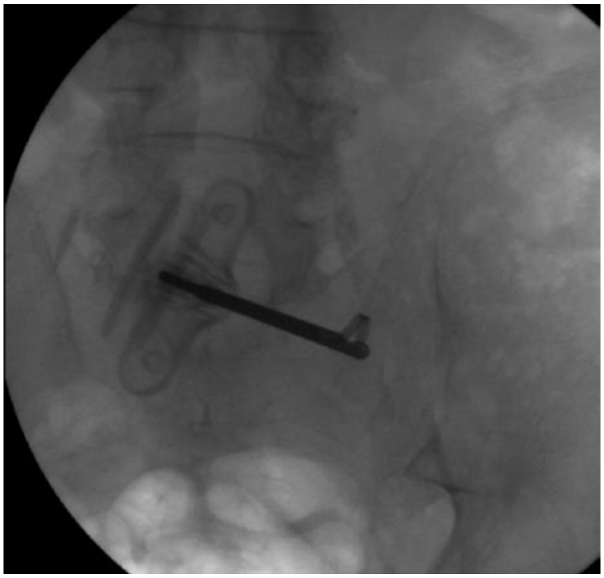

Fig. 13. *Cephalad deployment of the Arcuplasty blade AP view.*

Fig. 14. *Cement deposition into the lateral compartments of the sacrum in a patient with bilateral sacral insufficiency fractures AP view.*

the cannulas. The PMMA cement did indeed flow into the region where the internal osteotomies were performed and with more directional control away from the sacral foramen (Fig. 14). The procedure was successfully performed with a single cannula and osteotomy per side with excellent spread of cement deposition.

Discussion

The presentation of pain from sacral insufficiency fractures is a challenging condition that requires a high index of suspicion to diagnose along with obtaining specific imaging studies to accurately confirm the diagnosis. These fractures are more commonly discovered in patients known to be at risk for the more typical spinal vertebral compression fractures. These fractures can now be successfully treated by the controlled percutaneous delivery of PMMA cement into the substance of the fracture itself. In this study we established the reliability of fluoroscopic boundaries of the sacrum by placing cannulas into an excised sacrum under direct vision until the tip breached the cortical surface. Subsequent fluoroscopic images were obtained and confirmed the image boundaries correlated with the directly observed boundaries of the excised specimen. When the cement was delivered the sacral specimen itself was opened and the internal cement deposition was observed to be within the confines of the sacral cortical bone without extravasation through the cortex or the sacral neuroforamen. In this study, Kyphoplasty balloons were inserted prior to cement delivery that created intramedullary voids for the cement to preferentially deposit. The balloon Kyphoplasty technique has been previously described (9), and has been successfully utilized in several patients with good control of cement deposition. The Arcuplasty device has also been successfully used in several patients and was found to be effective in controlling cement delivery for performing sacral vertebroplasty. The Arcuplasty device does have the potential complication of blade fracturing with possible retained metal fragments; whereas, rupture of the Kyphoplasty balloon results in spillage of contrast but not retention of foreign material. The best method for treating sacral insufficiency fractures remains to be determined; however, the technique for cannula placement and PMMA cement delivery using fluoroscopic imaging is now more securely defined by whatever means or device a given practitioner chooses to use.

Acknowledgements

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