INTRODUCTION: Computed tomography (CT) is an invaluable tool in the management of orthopaedic problems, but the presence of artefact near instrumentation obscures image detail and impedes interpretation, affecting accurate determination of characteristics such as density near instrumentation.\(^1\) Using the human lumbosacral spine as a specific example, bone mineral density (BMD) varies by location within the vertebral body, as does the micro architecture and mechanical properties.\(^2\) The performance of instrumentation in vivo correlates with the quality of bone into which screws are placed,\(^3\) making the ability to assess bone properties within the region obscured by artefact important.

Measurement of BMD is a commonly used tool, but few have attempted to determine the BMD exactly where the instrumentation interfaces with the bone. To our knowledge, no technique has been described to use high-resolution qCT to accurately determine BMD along the trajectory of a screw in a non-destructive fashion.

The purpose of this paper is to describe and validate a technique for high-resolution CT imaging that allows accurate determination of BMD at the position of orthopaedic instrumentation. We will also describe the effect of titanium artefact on the accuracy of BMD measurements immediately adjacent to the implants.

METHODS: Nine fresh-frozen sacra had solid and hollow titanium screws placed into the S1 pedicles from a posterior approach. High-resolution micro-computed tomography (CT) was performed on each specimen before and after screw placement. All images were reconstructed with an isotropic spatial resolution of 0.308 mm, reoriented, and the pre-screw and post-screw scans were registered and transformed using a six-degree rigid-body transformation matrix. Once registered, two points, corresponding to the center of the screw at the cortex and at the screw tip, were determined in each scan. These points were used to generate cylindrical regions of interest (ROI) with the same size and trajectory of the screw. Figure 1 shows slightly staggered sagittal cuts of a representative specimen to show how the ROIs follows the size and trajectory of the screw. BMD measurements were obtained within each of the ROIs in the pre-screw scan. To examine the effect of artefact on BMD measurements around the titanium screws, nested annular ROIs of 1 mm thickness were created expanding from the surface of the screws, and BMD was measured within each in both the pre- and post-screw scans.

Figure 2 shows the first four 1 mm annuli starting at the screw-bone interface. All values for BMD are shown as mean ± standard error. The paired t-test was used for comparison of side-to-side differences.

RESULTS: The accuracy of registration between the pre- and post-screw scans was found to be 0.19 mm (CI 0.15 to 0.23 mm). Four specimens were scanned five times, and the error in registration ranged from 0.01 to 0.11 mm. Bone mineral density values were obtained for each of the cylindrical regions of interest. The values from the specimens that were scanned five times indicated a mean error of ± 2% in the BMD measurements. The differences between the solid screw and hollow screw were not significant (p = 0.23). The average BMD value for the ROI was 98.1 ± 9.8 mg HA/cc. Figure 3 shows the impact of the metallic artefact of the screws on the bone mineral density around the screws. For both screws, the change in BMD measurements follows an exponential decay curve. The majority of the artefact is found within the first 3 mm, but at 9 mm from the screws, the BMD is still 23% (CI 12-34%) higher than the pre-screw values near the solid screw, and 20% (CI 8-32%) near the hollow screw. At regions of interest as far as possible from the screws within the sacral cancellous bone, the values were consistently higher in the post-screw scans, averaging 23 mg HA/cc difference between the BMD calculated for the pre-screw and post-screw scans.

DISCUSSION: This technique is both precise and accurate. It improves on existing techniques of BMD measurement by allowing for more accurate registration through smaller voxel size and use of unique homologous characteristics of each sacrum. The ability to side-step the problem of artefact is an important step forward. Other techniques to reduce artefact do exist, but none are entirely successful.\(^1\) In specimens of poor bone quality, such as these sacra, significant inaccuracies can occur even at a distance from titanium instrumentation. By being able to calculate BMD exactly at the bone-screw interface, one can control for a variable in biomechanical testing more accurately. One also has the versatility to adjust for different screw lengths and diameters with this technique.

Current limitations to the application of this technique include: the need for manual selection of anatomical landmarks, the requirement for paired CT scans, and that this approach has not been demonstrated with living human subjects, as yet.

In summary, we have described a technique by which co-registered pre and post-screw CT scans can be used to obtain highly accurate BMD values in the precise location of the screw-bone interaction. This technique avoids the problem of artefact-related inaccuracies inherent in a single-CT scan approach to BMD values with metal in situ. Furthermore, we have demonstrated that the artefact created by the metallic implants can create large error in BMD values in osteopenic/osteoporotic cancellous bone, such as that found in this sacral model. This highlights the importance of this technique and its avoidance of such artefact.

REFERENCES: