Sparse-View Imaging with Equine Cone-Beam Computed Tomography

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INTRODUCTION: The incorporation of advanced imaging modalities, such as computed tomography (CT) has revolutionized the practice of clinical medicine. The high spatial resolution of CT makes it an inherently strong modality for the identification of subtle changes within bone. Preservation of this high spatial resolution while reducing scan times, minimizing image artifacts, and reducing radiation dosage to the patient (and operator) are all critical tasks in the evolution of CT technology. One method to reduce both scan time and radiation dose is via a sparse- or limited-view technique, which decreases the projection data required for image reconstruction. Reconstruction algorithms are primarily optimized for imaging of the thorax or abdomen in humans, but additional modifications can be made for imaging of musculoskeletal tissues. In addition to modification of reconstruction algorithms, CT systems can be modified to decrease scan time. Conventional CT utilizes a fan-shaped beam of ionizing radiation, while cone-beam CT (CBCT) utilizes a pyramidal-shaped beam. The main advantage of CBCT is that sufficient projection data for image reconstruction can be obtained following a single rotation of the gantry around the patient. The combination of newer iterative reconstruction techniques with CBCT has not yet been fully explored but holds monumental potential to achieve the highest quality image with the most efficient scan time. Previous work focused on the development of a novel CT image reconstruction algorithm (L1-norm), but this model has not been applied to a clinically-relevant CBCT dataset. The objective of this study was to apply and refine the previously developed image reconstruction algorithm for CBCT application and compare image quality to conventional methods.

METHODS: An equine distal limb, including the third metacarpal bone (MC3) and proximal phalanx, acquired from a racehorse euthanized for reasons unrelated to this study was used for imaging. An extensive volume of work has been published characterizing the effects of adaptive change within the MC3 bone of the Thoroughbred racehorse, making this an ideal biological specimen for evaluation. The imaged limb had a previously identified ovoid region of subchondral bone loss within the medial condyle of the distal MC3. The metacarpophalangeal joint was imaged using an equine-specific CBCT system (Pegaso, Epica Medical Innovations, San Clemente, CA, USA) with a technique of 100 kVP, 120 mA, 6 ms with a 360-degree rotation of the gantry, totaling 720 projections for image reconstruction. Raw projection data was then used to reconstruct images for comparison. Images were generated using the filtered-back projection (FBP) and L1-norm algorithms ranging between 720 and 32 views. Preliminary model development findings suggested a minimum of 64 views would be needed for diagnostic-quality image reconstruction. Additional images were generated using the L1-norm algorithm to compare (1) blurring across 0, 1, or 2 pixel widths, (2) modification of the L1-norm constraint parameter, and (3) variation in the number of views for sparse-view image reconstruction. Constraint parameters are used to optimize image reconstructed images from sparse sampling of projection data by integrating what is known about the data set to reduce artifacts. Outcomes of this study were purely descriptive in nature. Generated images were compared across algorithms for their diagnostic quality and selected to understand how modification of model parameters would optimize bone image quality. Conspicuity of the known subchondral lesion was evaluated in addition to the overall appearance of bone.

RESULTS: Sparse-view images were able to be successfully generated from the full CBCT dataset. Blurring across 1-pixel width resulted in superior image quality. Number of views was directly related to image quality, where the image quality at 128 views was superior compared to 64 and 32 views. No discernable improvement in image quality was observed >128 views (Figure 1A). At 32 views, streak artifacts began to substantially degrade image quality, and spatial resolution was markedly worsened; however, the subchondral lucency was still visible. Minimizing the L1-norm constraint parameter at 64 views resulted in a bone-centric image, where soft tissue attenuation and artifacts outside the bone were lost, and the bone tissue gray level appeared darker overall. Minimizing the L1-norm constraint appeared to increase spatial resolution. Titration of the L1-norm constraint parameter was possible to identify a value that did not compromise spatial resolution and preserved the attenuation of soft tissues adjacent to the bone. Images generated using the conventional FBP had an increased number of streak artifacts at all view numbers relative to images generated using the L1-norm algorithm 9Figure 1B). The pathologic lesion within the subchondral bone was visible in the FBP images.

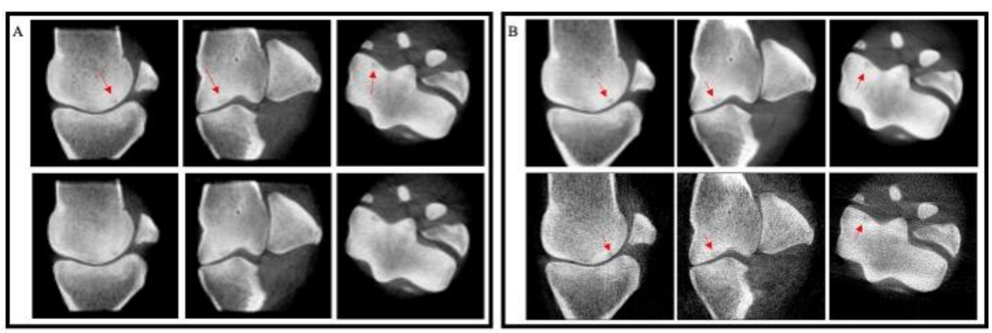

Figure 1. (A) Comparative images of 128 (top row) and 64 (bottom row) views of projection data using the L1-normal algorithm. The hypoattenuating lesion is observed within the subchondral bone. (B) Comparative images of 120 (top row) and 64 (bottom row) views of projection data using conventional filtered back projection. There is a substantial increase in streak artifacts.

DISCUSSION: The results demonstrate that sparse-view imaging with CBCT is a viable technique to generate diagnostic images of subchondral and trabecular bone. Even at 32 views, the pathologic lesion within the subchondral bone was visible, suggesting there may be clinical utility even with a very limited set of projection data. The increase in spatial resolution observed when the L1-norm constraint parameter was minimized is typically not the trend with other regularization techniques, however, the L1-norm algorithm was developed with a pixel (or voxel) sparsity focus ideal for imaging of bone. For imaging of bone using CBCT, the conspicuity of pathologic lesions within the subchondral bone can be increased with the application of novel algorithms, compared to conventional techniques. This study was intended to be a proof-of-concept exploratory study and further objective, clinical studies are needed to validate this technology.

SIGNIFICANCE/CLINICAL RELEVANCE: CBCT image quality of bone can be enhanced through modification of currently accepted algorithms that acknowledge the unique tissue properties of bone. The rapid acquisition of CBCT integrated with a sparse-view technique has the potential to be used as a clinical imaging tool for humans and veterinary species.

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