3D VOLUMETRIC IMAGE RECONSTRUCTION FOR PELVIC LIMB
DEFORMITY CORRECTION PLANNING
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Key Points
- The major benefit of three-dimensional volumetric reconstruction of CT images is that the image (volume) can be rapidly manipulated into the appropriate position to simulate the analogous radiographic views.
- Deformity correction planning from 3D volumetric reconstruction of CT images is more precise and accurate than planning using radiographic images.

Angular limb deformity correction and limb alignment to correct skeletal malalignment are commonly employed in small animal orthopedic surgery. Until recently, a unified system that was applicable to all deformities in all long bones was lacking in veterinary surgery. Recently, the Center of Rotation of Angulation (CORA) methodology has been described for use in deformity planning and correction in people, and several authors have adapted this system for use in dogs. The CORA methodology utilized an axis drawn along the long bone and two joint reference lines drawn across the joint at specific anatomic landmarks to develop reference angles for the proximal and distal joint of each long bone. Two axes exist in each bone; the anatomic axis is drawn from the center of proximal end of the bone to the center of its distal end, while the mechanical axis is drawn from the center of the proximal joint to the center of the distal joint. In bones such as the femur the mechanical and anatomic axes are different, while in other bones, such as the tibia, the axes are identical. The intersection between the joint reference line and the bone axis determine the joint reference angle.

Breed specific joint reference angle ranges have been developed from images of normal dogs, and these can be used to aid in the planning of deformity correction (Figure 1). Utilizing breed specific normal values, the magnitude and location of multi-planar deformities can be quantified in the frontal, sagittal, and transverse planes. In the event that breed specific values are not available, the opposite normal limb can be utilized to obtain joint reference angles for the individual patient. If both limbs are affected, the mean joint reference angles from the literature can be used. The joint reference angles are utilized to construct anatomic axis for proximal and distal bone segments. The CORA is located at the intersection of these anatomic axes, and its magnitude can be measured at this intersection (Figure 2). In most deformities, the CORA is uniapical in both the frontal and sagittal planes, however multiapical deformities do exist. Correction is typically undertaken at the location of the deformity in the frontal plane.

A closing wedge, opening wedge, or radial osteotomy can be performed. Each has advantages and disadvantages; for instance, the opening wedge increases limb length at the expense of stability, while the closing wedge provides a more stable construct with bone shortening. The radial osteotomy can be utilized close to joints, as the osteotomy location and angular correction axis (ACA) are at different locations (Figure 3). Stabilization can be performed utilizing bone plates and screws, linear external fixation, or circular external fixation.
**Figure 1:** Sagittal and frontal plane alignment determined by the CORA methodology. In the frontal plane, the Medial Proximal Radial Angle (MPRA) and the Lateral Distal Radial angle (LDRA) have been determined. In the sagittal plane, the Proximal Cranial Radial angle (PCRA) and the Distal Caudal Radial Angle (DCRA) have been determined.

**Figure 2:** A uniaxial deformity has been quantified in the frontal and sagittal planes using the reference angles from Figure 1. The location of the CORA in the frontal and sagittal planes has been identified.
3D Volumetric Reconstruction

Accurate radiographic assessment of limb alignment is difficult, and requires heavy sedation or general anesthesia and precise patient positioning to avoid positioning artifact. A complete radiographic evaluation includes at least cranio-caudal and medio-lateral views, as well as axial views if needed of the femur for torsion determination. Alternatively, a computed tomographic method with analysis of individual slices (Dudley 2006) or three-dimensional volumetric reconstruction with manipulation of the volume to represent views analogous to the radiographic images can be utilized (Figure 3).

The benefit of three-dimensional volumetric reconstruction of CT images is that the image (volume) can be rapidly manipulated into the appropriate position to simulate the analogous radiographic views. In a normal femur for instance, the magnitude of femoral varus (or valgus) is determined by measuring the anatomic lateral distal femoral angle (aLDFA) at the intersection of the femoral anatomic axis and the distal joint reference line of the femur, using the radiographic method described by Tomlinson (Tomlinson 2007) or the computed tomographic method described by Dudley (Dudley 2006). The volumetric reconstruction can be substituted for the radiographic view (Figure 1). In a femur with pathologic femoral varus or valgus, the femoral deformity is determined at the center of angulation of rotation (CORA) located at the intersection of the proximal and distal anatomical axes of the femur.

Femoral torsion can be quantified from the axial view of the femur. To obtain the axial view of the femur, position the patient in dorsal recumbency and flex the hip joint such that the x-ray beam is directed down the center of the femoral diaphysis, with the cassette under the hip joint. The femoral torsion angle (anteversion angle) is determined by the intersection of the transcondylar axis and an axis through the center of the femoral head and neck. The reported range for anteversion angle is quite broad, varies from study to study, and no breed specific normal values are available at this time. The mean reported in one study was 27 degrees (range 12-40 degrees). This is the value I generally use clinically, since this publication utilized a similar radiographic method. In the case of medial patellar luxation, if the patient’s femoral torsion angle is less than 27 degrees, I consider correction during corrective osteotomy. If the patient’s angle is greater than 27 degrees, I do not decrease the angle, as this may exacerbate medial patellar luxation. Again, three-dimensional reconstruction of the femur and manipulation of the view into the appropriate position is much more rapid and less labor intensive than obtaining this view with radiographs.

Since these radiographic views are difficult to obtain, and are highly sensitive to radiographic positioning artifact, several exposures of each view should be obtained. A variation of more than 2-3 degrees between radiographs or between left and right femurs in a symmetrically affected patient suggests positioning or measurement artifact.

In cases in which tibial torsional or angular abnormalities are evident, caudo-cranial and lateral views of the tibia including the stifle and tarsus should be obtained. Recently, computed tomographic evaluation of tibial torsion has been described, and this technique was found to be more accurate than the radiographic technique described by Slocum (Aper 2005, Apelt 2005).
Figure 3: Cranio-caudal, medio-lateral and axial three-dimensional volumetric reconstruction of the femur. These views were reconstructed from a transverse plane CT scan, 1 mm slice thickness.


