CORRECTIVE OSTEOTOMY – BRINGING THE PLAN TO THE BONE
(TRIGONOMETERY, GUIDE WIRES, SLA MODELING AND ART)
Randy J. Boudrieau, DVM, DACVS, DECVS
Cummings School of Veterinary Medicine at Tufts University, North Grafton, MA

Key Points
- Patient evaluation, re: gross weight-bearing assessment
- Radiographic planning: 2-D vs. 3-D assessment and their limitations
- Guide-wire techniques
- SLA modeling for complex 3-D deformities
- Final result dependent on all phases of planning and execution: preoperative planning (gross assessment, radiographs, SLA models), and intraoperative assessment and execution (guide-wire and gross assessment)

Using the Center of Rotation of Angulation (CORA) method for calculation of angular deformities enables the surgeon to determine with accuracy at what level, or levels, the deformity originates on the bone with a careful and systematic review of the radiographs. Although this has become a scientific method in humans, thanks to the efforts of Paley, transferring these methods to the canine (or feline) patient may be difficult as it assumes that these measurements can be transferred with accuracy onto the actual bone in the clinical case. There are a multiple of sizes and shapes, and conformations, not to mention the generally small size of our patients. Therefore, a number of additional aids are generally necessary so as to accurately transfer these measurements to the clinical patient, and also match the desired conformation of the specific breed involved.

In humans, weight-bearing full-leg anteroposterior radiographs are the gold standard for determining the mechanical axis of the lower limb as they account for the contribution of soft tissues to medial and lateral joint opening. With varus malalignment, for example, the knee joint opens laterally when weight bearing, resulting in a larger magnitude of mechanical axis deviation than can be accounted for by just the skeletal angulation. In veterinary medicine, weight bearing radiographs are not generally considered feasible due to the need to sedate the patients in order to obtain full compliance. Also, appropriate radiographic beam angulation is difficult to obtain.

It is therefore likely that standard radiographic or CT images performed in dorsal or sternal recumbency do not fully represent the contribution of soft-tissues to the overall limb axis. Therefore, limb alignment must not only rely upon preoperative radiographs, but direct assessment at initial orthopedic examination and again with intraoperative assessment. Accurate preoperative patient assessment may identify the soft-tissue contribution to the deformity, thus modifying the degree of surgical correction required. Regardless, 100% anatomic re-alignment may not be obtained because of these factors; therefore, a realistic expectation must be provided to the owner preoperatively.

Accurate transfer of the assessed correction to the patient must be achieved. There are a number of mathematical methods to inscribe a mark on the bone such that the degree of deformity correction can be fairly accurately performed. The classic is the simple closing wedge osteotomy that is performed in a single plane, and the example used is the cranial closing wedge osteotomy (CCWO) for decreasing the tibial plateau slope (TPS) of the proximal tibia (cruciate ligament deficient stifle joint for a
functional correction of joint instability). In this case fairly accurate assessments may be made of the TPS where the joint can be measured (and be verified to be) in the sagittal plane. Once the desired angle of correction is determined, it is a simple process to inscribe the appropriate marks to the bone. In this case, a line is inscribed on the proximal tibia perpendicular to the long axis of the bone (X). This distance is now measured directly on the bone (not the measurement obtained from the radiographs!), and with the angle of correction known (θ – from the radiographic determination), a vertical mark made on the bone to inscribe a right triangle (Y).

This distance is calculated from a simple trigonometric function: \( \tan \theta = Y/X \); or \( Y = X(\tan \theta) \). The wedge to be cut/removed is oriented in the frontal plane, which can readily be determined clinically. Alternatively, these marks for a known angle may be inscribed using a goniometer, or commercially manufactured wedges (Veterinary Instrumentation; Sheffield, UK). A rotational correction also can be easily performed – provided that the original line inscribed (X) is perpendicular to the long axis of the bone – whereby any rotation along this cut does not alter the axial alignment with the rotation. The amount of rotational correction performed is, however, difficult to determine from any radiographic evaluation. In clinical practice this is routinely performed by aligning known anatomic landmarks in the sagittal plane: alignment of the pes with the patellar tendon, thus maintaining the stifle and paw in the sagittal plane. Unfortunately, in other circumstances it is quite difficult to determine the actual amount of rotation required from preoperative measurements, and often these are only estimated from a gross evaluation of the standing patient preoperatively, and confirmed intraoperatively by subjective gross re-alignment.

There are mathematical methods to calculate rotation, but these require known fixed landmarks that can be observed on the radiographs and also reproduced on the bone. The classic example here is the determination of femoral head and neck anteversion. The femur can be positioned accurately in both the craniocaudal and lateral plane; the former by centering the patella with symmetric positioning of both fabella, and the latter by superimposition of both femoral condyles (this assumes no angular femoral deformities!). The center of the femoral head can be observed (and marked) on both radiographic views. From these radiographs the anatomic axis of the femur can be drawn, and a perpendicular line drawn to the center of the femoral head on the lateral view (A), and a line through the anatomic axis of the femoral neck with the center of the femoral head (B). Once again, the same simple trigonometric function of: \( \tan \theta = A/B \) can be used to determine \( \theta \). Two dimensional radiographs are, however, limited if there are additional deformities in the bone, and in this case, CT is much more accurate in determining the rotational deformity. Accurately transferring this rotational correction to the bone in the clinical case may be difficult if anatomic landmarks (e.g., pes and patellar tendon) cannot be used. Trigonometric methods can again be used to calculate the amount of rotation by either determining the chord of a circle with the rotation of correction and a known radius. A more accurate method is by using the arc of the circle, which can be inscribed onto the bone. The arc of the circle can be represented by the formula: \( \text{arc} = \theta/180^\circ(\pi)r \). These methods, however, assume a circular bone, which is not always the case.
One of the biggest issues when inscribing marks in our patients is the small size of not only the bone but also the angles that are being corrected. Within these small distances it is very easy to make small inscription errors that frequently can result in as much as 50% angulation errors.

Practically, even with these limitations, because of some of the severe deformities and the conformational differences between breeds, it may be necessary NOT to fully correct a deformity (e.g., Bassett Hounds), and instead only partially correct the deformity so as to match the opposite “normal” limb. One method to assure this occurs is to drape out both limbs in the surgical field simultaneously so that they can be constantly compared to each other throughout the surgical process. In addition, it is imperative that the entire limb be within the surgical field; especially important is full access to the joint above the level of the deformity, and in this example, to include to the level of the digits.

In order to determine a frame of reference, additional aids can be used to assess the limb malalignment and simultaneously aid with the corrections to be performed. These include gross overall assessment (and the reason the majority of the limb is included within the surgical field), and the use of “guide” wires. The latter are used to orient the frontal and sagittal planes with the joint center of motion, i.e., aligned with the joints above and below the deformity. In this manner, the deformity can be identified in all planes: angular deformities in both the frontal and sagittal planes, and any rotational deformity. Alternatively, if accurate preplanning has been performed, the start and end points of these wires (regardless of their initial position) defines the correction obtained. This guide wire technique has been described for radial/ulnar deformities in veterinary surgery, but it has been routinely used in human surgery for angular corrections, and can be applied to any bone/deformity.

Guide wires, or K-wires, are placed immediately above and below the CORA (providing adequate distance to perform the osteotomies within the confines of these wires). Each wire is placed such that it is parallel to the center of motion of the joint above and the joint below the deformity. In the case of distal radial deformities (carpal valgus, external rotation and cranial...
bowing), one K-wire is placed through the radial epiphysis parallel to the center of rotation of the antebrachiocarpal joint (A) (thus defining the abnormal position of the distal limb: carpal valgus and rotation). A second K-wire is placed in the distal metaphysis of the radius parallel to the elbow joint and its center of rotation (A) (thus defining the normal position of the proximal limb). Note that neither osteotomy cut accounts for rotation; this is determined only after the cuts have been made and aid the orientation and reduction before applying any fixation. These K-wires define the amount of deformity present and thus the amount of correction necessary in 2 of the 3 planes, which can be checked with the preplanning obtained from the preoperative radiographs. Both methods are used in order to provide maximal information before making any cuts (both methods should produce the same information; if not, an error has been made). The remaining deformity, cranial bowing of the distal radius, is addressed independently: the distal osteotomy cut is oriented not only parallel to the pre-placed distal K-wire, but also parallel to the distal radial joint surface (B). The guide wire method keeps the procedure “in the ballpark”, whereas the preplanning from the radiographs and/or CT using the CORA methodology fine tunes these corrections.

Further preoperative planning can be carried a step further with the reconstruction of 3-D images, and finally with stereolithographic (SLA) bone models. The latter are extremely accurate reproductions of the actual bone. Stereolithography allows the surgeon access to precise ex-vivo preoperative surgical planning with direct visual and tactile feedback, as the definitive surgical technique can first be performed on the model. Preoperative implant contouring/assembly also may be performed. In either case, considerable intraoperative time is saved, and any unexpected issues recognized preoperatively. Application of guide wires on the model also can help to determine the most favorable position for their placement and the most appropriate corrections (both direction and magnitude) that need to be performed. These maneuvers can be repeated directly on the patient – and with a great deal of accuracy.

Regardless of the methods used, it is imperative to consider a “check and balance” approach: accurate preoperative planning the not only is obtained from radiographs (and/or CT), but a gross assessment of the patient. Further preplanning can be obtained from SLA models, but not at the expense of eliminating one of the other techniques. And finally, gross intraoperative assessment is used to make the final determination, recognizing that the final result is a subjective evaluation of the overall procedure (keeping in mind the preoperative, weight bearing assessment). The cosmetic result will correlate to the functional result in the majority of the cases.


