Use of radiographic measures and three-dimensional computed tomographic imaging in surgical correction of an antebrachial deformity in a dog

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Case Description—A 1-year-old 7.4-kg (16.3-lb) castrated male mixed-breed dog was evaluated because of intermittent lameness and an antebrachial angular limb deformity.

Clinical Findings—The left forelimb had gross antebrachial external rotation (approx 90°) and marked procurvatum. Radiography revealed a severe partially compensated biapical antebrachial angular limb deformity. Measurements of medial proximal radial angle (MPRA) and lateral distal radial angle (LDRA) were obtained from orthogonal radiographs of the proximal and distal segments of the radius, respectively. Elbow joint-to-carpus translation was quantified. Deformities were localized and quantified by the center of rotation of angulation (CORA) method. Computed tomographic 3-dimensional image reconstructions of the antebrachium and carpus were completed to create 3 life-size stereolithographic models.

Treatment and Outcome—Two closing wedge radial osteotomies were performed at the level of the CORAs and stabilized with bone plates and screws.

Results—Frontal and sagittal plane alignments were corrected to 8° and 15°, respectively (reference limits, 0° to 8° and 8° to 35°, respectively). The MPRA was corrected from 55° to 68°, and LDRA was corrected from 32° to 76° (values considered normal are approx 85° and 87°, respectively). Elbow joint-to-carpus translation was improved by 42.5%. After 8 weeks, radiography revealed bone union. Owners considered the outcome acceptable, on the basis of limb appearance and lack of lameness at 1 year after surgery.

Conclusions and Clinical Relevance—A segmental radiographic planning technique combined with the CORA method, computed tomography, and stereolithography may be useful in the characterization of and planning corrective surgery for forelimb deformities in dogs.


ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>CORA</td>
<td>Center of rotation of angulation</td>
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<td>MPRA</td>
<td>Medial proximal radial angle</td>
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<td>LDRA</td>
<td>Lateral distal radial angle</td>
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<td>CT</td>
<td>Computed tomographic</td>
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<td>3-D</td>
<td>Three-dimensional</td>
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<td>FPA</td>
<td>Frontal plane alignment</td>
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<td>SPA</td>
<td>Sagittal plane alignment</td>
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A 1-year-old 7.4-kg (16.3-lb) castrated male mixed-breed dog was evaluated because of intermittent lameness of the left forelimb; the limb had a visible antebrachial deformity that resulted in gross external rotation of approximately 90° and marked procurvatum. The right forelimb had similar but much less severe deformities that were not quantified.

Standard orthogonal radiographic views of the right antebrachium, including the elbow joint and carpus, were obtained. As a result of the rotational severity of the deformity, accurate localization and quantification of the CORAs could not be accomplished because images of the entire proximal and distal portions of the radius could not be obtained in 1 exposure from any direction. Hence, independent segmental orthogonal radiographic views of the proximal and distal portions of the radius were obtained. For the proximal region of the antebrachium, the medial and lateral epicondyles of the distal portion of the humerus were used as anatomic landmarks to denote true medial and lateral aspects, and the x-ray beam was centered on the elbow joint to ensure accurate cranial-caudal positioning of the proximal portions of the radius and ulna (Figure 1). A similar process was then completed for the distal portion of the radius; the cranial surface of the metacarpal bones was used to denote true cranial and caudal aspects. This unique segmental radiographic technique enabled application of the CORA principle for determination of the relationship of the anatomic axis of the radius to the elbow and carpal joints.¹

Radiography of the elbow joint revealed rotational radial head subluxation; the distal portion of the humerus was evident in the cranial-caudal radiographic view.
The dog was premedicated, and anesthesia was induced and maintained as for the CT examinations. Perioperative antimicrobial prophylaxis (cefazolin so-
27 mm proximal to the distal osteotomy closure on the cranial-lateral surface of the radius. Osteotomies for this closing wedge were made in identical fashion, and the resulting 30° wedge of bone was removed. The ulna was osteotomized at the same level through a small caudal approach. The entire distal segment was then rotated internally approximately 40° from its original axial position. A 2.0 dynamic compression plate and 6 cortical screws were applied to the cranial-lateral surface of the radius with 3 screws in the proximal radial segment and 3 screws in the intermediate radial segment, following standard principles of internal fixation. To confirm appropriate osteotomy placement and correctional limb rotation during surgery, the intact and corrected stereolithographic models were used as a template for plate contouring. A cancellous bone graft was harvested from the proximal portion of the humerus and applied to the 2 osteotomy sites. All incisions were closed in a routine manner.

No surgical complications were encountered. Gross observation of the limb in the immediate postoperative period revealed an apparent appropriate correction of the rotational and angular deformity. Among the standard postoperative orthogonal radiographic views obtained, the cranial-caudal view allowed the MDRA and LDRA to be quantified; from these assessments, it was confirmed that the rotational component of the deformity was improved, obviating the need for postoperative segmental orthogonal radiography (Figure 3). After surgery, MPRA and LDRA were 68° and 76°, respectively, and FPA and SPA were 8° and 15°, respectively. In addition, radiographically measured elbow joint-to-carpus translation, defined by the displacement of the center of the elbow joint to the center of the carpus in the frontal plane, was reduced from 45 mm to 26 mm (Figure 4).

A bivalved fiberglass cast was placed on the left forelimb from the distal phalanges to the level of the proximal region of the olecranon for added protection during healing. The dog recovered from anesthesia without complication and was discharged to the owners with instructions for strict cage confinement and weekly bandage changes. The dog was also to be administered carprofen (2.2 mg/kg [1 mg/lb], PO, q 12 h), tramadol hydrochloride (3.0 mg/kg [1.36 mg/lb], PO, q 12 h), and cepalexin (22 mg/kg [10 mg/lb], PO, q 12 h).

The dog was reevaluated at 4 weeks after surgery and had no signs of complications. Owner compliance was reported to be appropriate (including provision of cage rest, leash walks only, restricted activity, and weekly bandage changes by referring veterinarian), and the dog had tolerated the cast well. The cast was removed for radiographic evaluation, which revealed appropriate progression toward healing of the osteotomy sites and no implant changes or complications.

Figure 2—Three-dimensional CT reconstruction (A) and stereolithographic model (B) of the antebrachium of the left forelimb of the dog in Figure 1. In panel A, notice the severe radial procurvatum and external rotation along the entire length of the radius. In panel B, the model is viewed with the proximal segment placed in true cranial-caudal orientation.
The osteotomy sites were still radio graphically visible, but the margins were rounded and irregular. The cast was reapplied and the dog was discharged from the hospital; owners were given instructions to continue strict cage rest for 4 additional weeks.

At 8 weeks after surgery, the dog was evaluated again and no complications were detected. Radiography revealed that the radial osteotomies were sufficiently healed to permit removal of the cast, although the ulnar osteotomies had not yet achieved clinical union. The osteotomies of the radius were less distinct as a result of callus formation along the radius; there was evidence of disuse osteopenia of the distal portion of the limb as well. The implants remained in position with no evidence of loosening (ie, no change in position or lucency around the screws). The cast was removed and the dog was discharged from the hospital; the owners were instructed to allow the dog to slowly return to normal activity over a period of 4 weeks. One year after the procedure, the owners reported that the dog’s lameness had improved substantially, compared with the level of lameness before surgery; recurrence was intermittent and barely perceptible. The dog’s activity level was unim peded by any residual limb impairment. The owners also reported satisfaction with the outward appearance of the limb.

Discussion

Angular deformities of the forelimb are frequently reported problems in dogs.\textsuperscript{1,2,5,6} In 1 study\textsuperscript{1} of forelimb deformities in dogs, 75% were attributable to distal ulnar physis abnormalities. Such abnormalities can be relayed to a multitude of etiologies.\textsuperscript{1,7-10} However, trauma is the most common cause of early physis closure.\textsuperscript{11} Many surgical techniques and associated preoperative planning methods have been described to correct these deformities.\textsuperscript{2,5,6,12-15} Recently, a method of deformity localization and quantification of the CORA in the antebrachium of dogs has been used; this is based on correcting the affected bone’s mechanical or anatomic axis to meet apparently normal parameters.\textsuperscript{2,16} The typical relationship

![Figure 3](image-url) Medial-lateral (A) and cranial-caudal (B) radiographic views of the left antebrachium of the dog in Figure 1 immediately after surgery to correct the angular deformity. Notice that both the elbow joint and carpus can be viewed in true medial-lateral or cranial-caudal orientation without the use of segmental radiography, indicating correction of the rotational component of the deformity.

![Figure 4](image-url) Cranial-caudal radiographic views of the left antebrachium of the dog in Figure 1 before (A) and after (B) surgery to correct the angular deformity. Elbow joint-to-carpus translation is determined as the distance between lines drawn perpendicular to the joint reference line of the elbow joint through the center of the elbow joint and through the center of the carpus (yellow lines). Following surgery, the elbow joint-to-carpus translation has been reduced from 45 mm to 26 mm.
of the radial anatomic axis to the associated joints in clinically normal dogs has allowed this method to be used in dogs with abnormal findings. To our knowledge, surgical planning and execution of antebrachial angular limb deformity corrections have been previously based on measurements obtained from orthogonal radiographic views. In a clinically normal dog, the carpus and elbow joint lie approximately in the same frontal plane (evidenced by the appearance of both the elbow joint and carpus in a single craniocaudal radiographic view); the same applies for the elbow joint or carpus in the sagittal planes. However, with severe rotational deformities, orthogonal radiographic views alone may not allow the accurate determination or measurement of deformities in the frontal and sagittal planes. In regard to these deformities, the rotation within the radius or ulna results in the carpus and elbow joint aligned in different planes. Thus, in the dog of this report, a novel orthogonal segmental radiographic technique, 3-D CT reconstruction, and stereolithography were used to aid in the diagnosis and quantification of a severe biapical antebrachial deformity that included excessive procurvatum, varus and valgus deviations, and marked external rotation. These procedures also assisted in planning of the surgical correction of those abnormalities. Recently, the use of 3-D CT image reconstruction and stereolithography to aid in correction of a pelvic limb deformity in a dog has been described. To our knowledge, the stereolithographic technology in conjunction with the novel radiographic approach used in the dog of this report has not been previously described for the assisted surgical planning and correction of an antebrachial angular limb deformity in dogs.

A major limitation of this case report is that the degrees of the dog’s lameness before and after surgery were not objectively quantified. Thus, success was defined by the radiographic and gross improvements in limb alignment and the subjective lameness assessment by the clinicians and owners, which may be biased.

The dog of this report was deemed a surgical candidate because of the severity of the lameness and the assumption that the lameness may have worsened without treatment. Angular limb deformities can result in abnormal distribution of forces across adjacent joints, joint misalignment, and, potentially, subluxation; these factors may result in osteoarthritis, lameness, and signs of pain. In the dog of this report, severe antebrachial rotation resulting from the underlying external rotation of the entire radius with concomitant radial head subluxation (as revealed by radiography and 3-D CT reconstruction imaging) was detected. There were multiple reasons for this dog to become increasingly lame, including elbow joint and carpal joint osteoarthritis, elbow subluxation, consequences of any component of the antebrachial angulation (radial-ulnar rotation, procurvatum, or varus or valgus deformities), or the resulting elbow joint-to-carpus translation.

Recently, a technique to reduce radial head subluxation with a traction device consisting of stopper wires and external fixation in dogs and cats has been described. Many of the animals studied in that investigation were skeletally immature, thereby potentially having some osteochondral plasticity and capacity for remodeling. In the dog of this report, CT and stereolithography of radial head morphology revealed congruity with the humeral condyle, despite the external rotation of the radial head. Thus, on the basis of the abnormalities and age of the dog of this report, we concluded that surgical alteration of the radial head may have resulted in the loss of humerus-radius congruity. The positive outcome in the dog of this report suggests that radial head subluxation in skeletally mature animals (in which compensatory remodeling has already happened naturally to optimize humerus-radius congruity) may be left uncorrected. However, definitive studies would need to be completed to substantiate this claim.

Stereolithography is a type of rapid prototyping technology that converts computer-aided design information obtained from a CT scan to a format from which 2-dimensional data slices are created. The converted data are then used by the stereolithographic machine to make the 3-D model 1 layer at a time with low-powered UV lasers and epoxy resin. During the process, the resin is cured to create solid slices (or layers) that are stacked together to form the model, which is then further cured in a UV light oven. The accuracy of the model is ultimately limited by the resolution of most CT scanners and generally not the stereolithographic process. Stereolithography was first described for use in surgical planning in humans in 1992 and has since become popular and useful for various types of surgery, including craniomaxillofacial surgery, skeletal anomaly repair, prosthesis implantation or arthroplasty, and acetabular fracture repair. Recently, the use of stereolithography to aid in surgical repair of a bilateral pelvic limb deformity in a dog has been reported. However, to our knowledge, there are no previous veterinary studies to evaluate the advantages and disadvantages of the use of stereolithography for angular limb deformity diagnosis, surgical planning, or surgical correction in dogs.

The planning methods used in the dog of this report may help to determine the practicality of and true indications for a given procedure and may potentially predict possible complications in other animals. In the instance of angular limb deformities, a model of the affected bone allows the surgeon not only to view the deformity in a tangible state but also to perform a rehearsal surgery prior to performing the actual surgery in a live animal. This additional planning and rehearsal surgery may benefit the patient by increasing surgeon confidence and decreasing the durations of surgery and anesthesia. Ultimately, these potential benefits may decrease patient morbidity and overall cost to the client. One study in humans to evaluate the usefulness of stereolithography in craniomaxillofacial surgery for client education, diagnosis, and operative planning revealed increased diagnostic capabilities, improved operative planning, and reduced operating time, compared with standard imaging procedures (eg, radiography, CT, magnetic resonance imaging, and digital subtraction angiography) alone. Therefore, the use of stereolithography appears to have an exciting and promising future in veterinary medicine.

Published mean ± SD values of MPRA and LDRA in apparently clinically normal dogs are 85.3 ± 3.5° and...
86.7 ± 2.9°, respectively. In the dog of this report, the MPRA was corrected from 65% to 80% of the published reference mean value, and LDRA was corrected from 37% to 87% of the published reference mean value. Although the MPRA and LDRA were not corrected to within 100% of the accepted normal limits, the achieved MPRA (8°) and SPA (13°) were corrected into the ranges reported to be normal (ie, 0° to 8° and 8° to 35°, respectively). Additionally, the radial translational defect was corrected by 42%. Although there are no published data for apparently normal elbow joint-to-carpus translation in dogs, the improvement in the dog of this report was subjectively considered to be adequate for regaining a more aligned radioulnar mechanical axis. Additional studies in dogs need to be completed to determine the critical degree of elbow joint-to-carpus translation that results in lameness, if any. To our knowledge, no published data have established minimum percentage of radiographically measured improvement in any of these variables (MPRA, LDRA, FPA, SPA, or elbow joint-to-carpus translation) required to result in patient improvement and owner satisfaction. Further studies are indicated to determine these values and thereby provide additional information when planning the surgical correction of an antebrachial deformity in dogs.

As a result of the treatment of the dog of this report, we concluded that the aforementioned additional diagnostic and planning methods greatly benefited the management of severe antebrachial deformations. These methods provided supplemental information for the diagnosis of and assessment of the severity of the deformity, increased the surgeon’s knowledge and confidence prior to surgery, promoted surgical efficiency, and potentially reduced the duration of surgery and anesthesia. Furthermore, the CT and stereolithographic data provided support for the use of a novel segmental radiographic technique in animals with severe angular deformity in which severe bone rotation interferes with the determination of joint reference lines and bone anatomic axes.

References