OVERVIEW OF ALGORITHM FOR MANAGEMENT OF ANTEBRACHIAL GROWTH DEFORMITY IN DOGS. INCLUDING THE DAPPER FRAME AND DOME OSTEOTOMY

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ETIOPATHOGENESIS
Deformities of the canine antebrachium may occur for a number of reasons and may affect the radius or ulna or both bones. Premature closure of the distal ulnar physis accounts for approximately 75% of deformities, generally perceived to be genetic in origin in predisposed (often chondrodystrophic) breeds, but can often occur following trauma because of the intrinsic susceptibility of the distal ulnar physis to asymmetrical crushing injury imparted by its conical profile and high relative growth rate. Other possibilities include partial or complete premature closure of the distal or proximal radial physis, heritable or genetic disorders (e.g. ectrodactyly), endocrine disorders (e.g. congenital hypothyroidism, pituitary dwarfism), drug reactions (e.g. fluoroquinolones), metabolic or nutritional disorders (e.g. rickets) and other miscellaneous skeletal abnormalities (e.g. synostosis or malunion secondary to fracture or osteotomy, retained cartilaginous cores, hypertrophic or metaphyseal osteopathy, subchondral bone cysts).

In many cases, by the time deformity has developed, the underlying cause cannot be definitively identified or has been overshadowed by secondary changes (e.g. secondary physeal closure), but care should be taken to exclude causes that may require ongoing treatment or affect long-term prognosis such as nutritional or endocrine disorders.

DEFORMITY COMPONENTS
Components of antebrachial growth deformities (ABGD) may be highly complex, largely attributable to the two-bone system of the radius and ulna, including their complex three-dimensional relationship (with the ulna spiralling from caudo-proximal to latero-distal in the normal dog), and biomechanical interaction which includes formation of the elbow articulation, affording stability to the carpus, and attachment via the interosseous and annular ligaments. Such complexity is seldom encountered with the more easily quantified deformities of the tibia and fibula, likely attributable to the relative biomechanical dominance of the tibia.

Deformities may be categorized by the following components:

- Cranio-caudal (radius curvus)
- Medio-lateral (valgus / varus)
- Rotational deformity about the long axis of the antebrachium
- Translation between the elbow and carpal joints

The specific components of osseous deformity may depend largely on the underlying etiopathogenesis, including the complete or partial (and symmetrical) nature of physeal closure, the proximo-distal orientation of major etiopathogenic effect, and age of onset (particularly with reference to strength of surrounding soft-tissues and potential for compensatory growth).

Secondary effects of deformity may include joint incongruity or dysplasia (including humero-ulnar or humero-radial subluxation), carpal deviation and progressive soft-tissue laxity, pain and osteoarthritis of surrounding joints (including of the manus if foot placement is affected).

Many dogs are affected by multiple deformity components, at least at the time of diagnosis, and may have some degree of compensatory change (either osseous or soft tissue).
DEFORMITY CORRECTION

Where deformities are limited to single entities without complex directional change of bone growth, they may be addressed relatively simply, whilst other more complex deformities may require specific configurations of osteotomy and fixation systems.

One of the key interventional elements of some of these techniques is a novel bi-oblique dynamic proximal ulnar osteotomy (BOD-PUO) which has been suggested by the author. The cut is made in the proximal ulnar diaphysis distal enough to the H-R joint to control excessive movement of the proximal ulnar segment via soft-tissue attachments, but proximal enough to facilitate motion of the proximal ulna under pull of the triceps attachment without producing a non-union. The cut is generally 3-6cm distal to the H-U joint, depending on breed, and the saw blade is held parallel with the caudal cortex of the proximal ulna/olecranon (not the distal ulna) and as tightly against the caudal ulnar margin as possible, such that the cut trajectory is long and very oblique – usually 20-40 degrees in both the caudo-distal and the proximo-lateral to disto-medial trajectories.

SINGLE-COMPONENT DEFORMITIES

1 Humero-radial incongruity (HRI):
Where this is the only deformity due to disruption of radial physeal growth but there is no angular component to deformity and the ulna is unaffected, the following surgical options may be employed.

A Ulnar shortening performed via PUO: We do not recommend this for HRI > 4-5mm. Ulnar ostectomy can be performed, but is not recommended without pin stabilization proximally and if performed distally may not allow adequate correction.

B Radial distraction osteotomy can be performed transversely or obliquely.

(i) Oblique osteotomy with transarticular distraction is recommended for HRI 4-10mm, depending on patient size, such that the proximal and distal segments stay in contact during lengthening. Distraction in these cases is performed using either wires in the distal humerus and proximal radius tensioned bilaterally using linear fixator components, sprung wires subtended from a proximal ulnar hybrid frame or transverse pins in the humerus, radial head and proximal ulna attached bilaterally using anchors and elastic bands.

(ii) Transverse osteotomy with distraction osteogenesis is recommended for HRI greater than approximately 8mm, depending on patient size, using a standard circular/wire frame.

2 Humero-radial incongruity (HRI) with a short antebrachium:
Transverse proximal diaphyseal radial osteotomy and oblique proximal diaphyseal ulnar osteotomy (at different levels to prevent synostosis) with distraction osteogenesis is recommended using circular/wire frame components. The HRI is corrected first using a two-part circular frame, the bottom portion of which is connected via a rigid linear component to the Olecranon and proximal ulna. When HRI has been addressed, the linear proximal ulnar component is detached from the distal circular frame component and anchored to the proximal circular component. Distraction then continues to facilitate antebrachial lengthening.

3 Humero-ulnar incongruity (HUI) and Ulnar notch incongruity:
The BOD-PUO described, in the author’s experience, can allow motion of the proximal ulna in transverse, sagittal and torsional planes and may address humero-ulnar conflict from several potential etiologies.

4 Premature closure of distal ulnar physis before development of functionally significant radial deformity:
Aggressive distal ulnar osteotomy with removal of periosteum is indicated, especially in young large-breed dogs with a propensity for rapid re-growth which may require repeat osteotomy. Owners should be pre-warned in this regard. Ancillary fixation is unnecessary.

Surgery Chapter
5 Radial Head Luxation:
Relocation of radial head luxation in juvenile patients where bone plasticity may facilitate appropriate remodelling to reconstruct a functional articular surface may be beneficial compared with non-surgical management or radial head excision arthroplasty. This can be achieved by application of various techniques, but the author advocates progressive relocation over a period of days-to-weeks, allowing the bone to remodel prior to full load-bearing. Traction may be applied to the radial head using olive (stopper) wires attached to an external fixation arch component which is driven in the direction of intended translation (disto-medially) by linear motors mounted off a rigid arch-pin frame on the proximo-caudal ulna. Use of an oblique “sliding” radial osteotomy may help retain appropriate osseous contact and callus distraction during translation (callotasis). The technique affords significant control of radial head position by comparison with ostectomy techniques for radial head relocation.

It is also of note that most complex ABGD configurations observed by the author have some degree of radial head subluxation as an integral component of the deformity and that this may significantly contribute to the degree of torsion observed, which can be more related to elbow subluxation in the author’s opinion than actual radial torsion as measured on CT scan. This is under-reported in the veterinary literature due to inability to appreciate or measure this phenomenon on standard projectional radiography in the author’s opinion.

COMPLEX DEFORMITIES

Planning
Various methods of pre-surgical planning for the correction of ABGD in dogs have been described and are aimed at identifying and quantifying the components of deformity present. All published veterinary reports to date use the anatomic axis of the radius and a range of landmarks or other axes in order to radiographically identify the point(s) of maximum deformity, and much is derivative of the extensive and seminal published works of Dror Paley MD FRCSC with regard to the human pelvic limb.

The centre of rotation of angulation (CORA) technique has been described for measurement of antebrachial deformities in canine patients (Fox et al, 2006) and represents perhaps the most complete radiographic measurement technique available. The axis around which the bone segments, after an osteotomy, are rotated is called the angulation correction axis (ACA). When the osteotomy and the ACA pass through the CORA, realignment occurs without translation. When the ACA passes through the CORA but the osteotomy is at a different level, the axis will realign with angulation and translation at the osteotomy site. When the osteotomy and the ACA are at a different level from that of the CORA, a translational deformity will result (secondary translation).

While highly reproducible in one-bone models (such as the femur) or in limited two-bone models (such as tibia/fibula), CORA technique has several potential weaknesses when applied to clinical canine ABGD:

1. Joint incongruence or dysplasia (particularly of the elbow) may be a common finding, making measurement of joint angles based on articular landmarks challenging. Deformities are commonly located immediately adjacent to joint surfaces (particularly with physeal injuries), necessitating accurate identification of articular landmarks to localise deformities.
2. Some reported techniques are focussed on identification of radial deformity alone, based on the assumption that ulnar deformities are of lesser clinical significance.
3. Where rotation exists (as it does in almost every case seen in our clinical practice), and particularly when subsequently surgically addressed, there are two major effects:
   a. Magnitude of rotation cannot be accurately identified radiographically.
   b. All measurements of angular and translational deformity are also inevitably (and unpredictably) skewed due to the abnormal spatial relationship of standard landmarks.
4. Radiographic measures are only applicable to assess osseous and static deformities. Dynamic carpal or other soft tissue laxity (common with rotational and varus/valgus deformity) cannot be radiographically evaluated but may be an important factor when considering surgical intervention.
5. CORA methodology identifies changes compared with what might be considered “normal” limb conformation. Unilateral deformities allow comparison with the contralateral limb as a reference, but in many patients, deformity may be bilateral. Furthermore, many affected dogs are of small or chondrodystrophic breeds which may not confirm to reference ranges established for dolichocephalic breeds.
6. Care must be taken to evaluate all bones in the affected limb (particularly the humerus with reference to ABGD) to examine the possibility of compensatory changes, especially with regard to the humeral condylar transverse axis, which might affect the outcome of subsequent surgical management.

Surgery Chapter
Independent segmental orthogonal radiographs of the proximal and distal radius and the use the CORA methodology after conceptual juxtaposition has been described (Dismukes et al, 2008). However, this may be a more speculative rather than accurate method of measuring the magnitude and point of the deformity, and may be challenging in the face of multi-apical deformities.

Computed Tomography (CT) has been reported to assist with preoperative planning (Dismukes et al, 2008) of complex ABGD of the dog, and is considered the gold standard for measurement of rotational deformity in human limbs. Though the technique has obvious advantages, the necessary facilities are not yet available to the majority of veterinary health providers worldwide. Furthermore, although methodology is such that rotation can be accurately estimated in the presence of known frontal or sagittal plane deformity (Meola et al, 2008) using a reconstruction technique, further evaluation of this technique in clinical cases and commonly-affected breeds is warranted.

It is worth remembering that planning need only be as accurate as can be reliably achieved at surgical intervention. Any intra-operative changes to a single component of the proposed “plan” as determined from pre-operative imaging will affect all other components. For example, if rotational deformity is corrected based on visual intra-operative measures, or if an osteotomy is performed proximal or distal to the planned location, all planned measurements for correction of sagittal or frontal plane alignment become invalid.

Stereolithographic prototyping from CT images has been reported (Dismukes et al, 2008) and holds significant advantage regarding pre-operative planning, surgical rehearsal and teaching, but is not widely available, may be financially prohibitive and may fail to provide information regarding soft tissue contributions to limb alignment and function.

In humans, use of “hands-on” measurements, including use of a torsiometer have been shown to be as reliable as CT measures for assessment of tibial torsion (Sestan et al, 2008). The author submits that physical assessment of limb conformation including manipulation of carpal and elbow joints through a full range of movement to assess their rotational relationship and soft tissue contributions to overall limb alignment should be considered equally if not more important than measurements of limb conformation attained from diagnostic imaging. This functional mechanical joint axis realignment technique with appropriate internal or external fixation has been successfully employed by the author in a large case series.

**Aims of surgical intervention**

Major aims of surgical intervention should include restoration of elbow congruity and limitation of progression of elbow and carpal laxity and osteoarthritis. Correction of varus / valgus and rotational anomaly are considered most important in this regard, with management of radius curvus or translational deformity being of lesser significance, although significant translational deformity may result in ectopic joint-loading. The overall goal is to establish the optimal functional limb axis and permit pain-free limb use.

Secondary aims include preservation of cortical alignment to allow bone healing, prevention of further deformity and correction of limb length disparity.

**Treatment options**

In cases where function is minimally compromised and long-term progression of osteoarthritis is expected to be limited, conservative management or appropriately oriented trans-physeal bridging to re-direct and harness residual growth may be justified. Cosmesis alone is never a justifiable reason for intervention and breed conformational differences must be accommodated when considering surgical intervention. Surgical intervention is only ever justified in the opinion of the author if the deformity results in dysfunction impairing quality of life.

Simple transverse, oblique, closing wedge, opening wedge, stairstep, complex wedges and dome osteotomies have been described for the correction of canine antebrachial deformities. Type of osteotomy selected will be dependent on the type of correction required. For simple derotational osteotomies, a transverse osteotomy is ideal. For more complex corrections, opening and closing wedges may be used, but dome osteotomies or oblique osteotomies may be preferable for maintenance of contact of the osteotomized ends to facilitate bone healing. Osteotomies termed “dome” to date have generally involved the use of an arcuate blade which allows motion in one plane primarily, with only limited capacity for ancillary directional orientation. True dome osteotomy is now a reality and clinical application by the author has yielded encouraging results.
Antebrachial shortening may prompt requirement for significant limb lengthening by distraction osteogenesis and may necessitate use of complex external skeletal fixation configurations with different frame units performing different functions at various levels of the antebrachium.

A range of stabilization techniques are available:

1. Internal plate and screw fixation is feasible but can only be performed where acute correction is possible. Plate contouring can be challenging where rotational corrections are performed due to the ellipsoid cross-sectional shape of the radius which creates a step when rotated, and fixation may be challenging where correction very close to the carpus or elbow is required or where implants must be placed through particularly narrow bone dimensions. Generally segments are temporarily stabilized using k-wire fixation before plate and screw application. Maintenance of precise reduction during application of the plate and screws may also be challenging, particularly in smaller patients where placement of temporary interfragmentary pins may be challenging.

2. Locking plate fixation is particularly useful in this application, allowing limited numbers of small diameter screws to provide rigid fixation and avoid soft tissue structures such as the extensor tendons when small juxta-articular segments are anchored. Low-profile implants are recommended.

3. Linear external skeletal fixation (LESF) has been reported for management of antebrachial deformities. Application is typically limited to acute corrections or limited progressive distraction osteogenesis scenarios. Advantages over plate and screw fixation systems include elimination of requirement for plate contouring and ability to stabilize small bone fragments where corrective osteotomy is performed close to a joint surface. It is significant that Type II medio-lateral or Type III LESF frames are typically considered to be required to afford adequate stability for osteotomy healing, particularly for less stable osteotomy configurations. There is distinct disadvantage to placement of full-pins in the radius, attributable to the ellipsoid shape, both with regard to pin insertion at the most convex surface of the bone, and with regard to potential for fracture through pin tracts. Inter-osseous arterial haemorrhage may be an additional consideration. The author does not recommend this fixation modality due to lack of versatility and availability of superior options.

4. Circular external skeletal fixation (CESF) systems encompass the advantages of LESF regarding stabilization of small or irregularly-shaped bone segments but also allow progressive correction of angular deformities and distraction osteogenesis if required. Biomechanically, axial micromotion afforded may be beneficial for promotion of osseous healing. The major disadvantages are the requirement for specialized instrumentation and skills, bulk of the apparatus required (particularly for multi-apical deformities in small breed dogs requiring progressive correction), potentially prolonged surgical time and requirement for precise and technically demanding pre-operative planning and execution.

5. Hybrid external skeletal fixation (HESF) systems potentially combine the advantages of both LESF and CESF. They are most applicable for acute corrections but can be modified to allow for distraction osteogenesis or progressive corrections if required. Fixation of small fragments with freedom of pin placement in multiple planes is facilitated while frame bulk is generally less than that employed for CESF. Limited axial micromotion is possible dependent on frame design. Application and planning generally require less technical skill and accuracy compared with CESF systems, as there is typically greater potential for post-operative frame adjustment. Linear - Hybrid frame constructs have been reported, using a full ring distally with Type 1A, 1B or II linear components proximo-medially and/or proximo-laterally. (Sereda et al, 2009) and can be successfully applied with relatively simple technical application. However, moderate accuracy of distal wire placement and osteotomy location are still required for successful application.

6. A Double Arch Pin Poly-directional External Realignment (DAPPER) frame has recently been evaluated and successfully applied in dogs by the author. The advantages of simplified pre-operative planning, technical application and reduced surgical time are optimized, while retaining versatility of fixation including of small bone segments. Acute correction is necessitated, but manipulation in six degrees of freedom is straightforward, allowing for simultaneous correction of rotational and angular deformity without compromise of stability or fixation. Post-operative manipulation is facilitated. The configuration can be converted via linear motors to a distraction frame where necessary. The author has successfully employed the DAPPER technique using conventional osteotomies at the apex of deformity as defined by CORA methodology and more recently using a novel spherical osteotomy blade, which may allow greater versatility of manipulation of osseous segments. (Abstracts 1 and 2)
A major limitation of all listed management modalities is that they are all directed toward osseous correction. The role of soft tissues in antebrachial deformity cannot be underestimated. Joint laxity, particularly of the carpus may be central to achieving positive clinical outcome, and may require “overcorrection” of valgus osseous deformity to achieve optimal functional limb axis. Occasionally pancarpal arthrodesis is a necessary adjunctive surgery to ensure pain-free limb use. Restraint on osseous correction intrinsic to antebrachial muscles and tendons, particularly during limb-lengthening procedures and attempts to address profound radius curvus, is a further limitation, and may preclude complete correction in some cases. Recognition of this pre-operatively is essential when employing techniques where intra- or post-operative modification is not straight-forward.

SUMMARY
Identification and management of antebrachial growth deformities in small animals are challenging due to the two-bone model and complex interaction of the radius and ulna, particularly at the elbow joint. Conventional planning techniques developed for application in one-bone or limited two-bone models may have significant weaknesses and should be applied with caution. Management of various deformity components should be carefully prioritized. Failure to correct all components of deformity may still be compatible with functional pain-free outcome and may significantly simplify methodology while reducing financial cost and potential morbidity. Various surgical techniques are available, but use of arch-pin frame configurations or locking plates in conjunction with true spherical dome osteotomies may offer attractive versatility in many circumstances and constitutes the current preference of the author when addressing complex antebrachial deformities.

ABSTRACT 1
Clinical Comparison of Linear-Arch and Double-Arch Pin Fixator constructs for Acute realignment of Antebrachial growth deformity in dogs

INTRODUCTION
Surgical intervention for antebrachial growth disturbance addresses components of frontal, sagittal, rotational and translational deformity. The surgical goals are establishment of functional limb axis and avoidance of elbow and carpal pathology resulting from deformity. Oblique, cuneiform, stair-step and dome osteotomies have been described with internal or external fixation systems. Internal fixation systems require preoperative planning and are limited for correction of rotational deformity. External fixation systems described include linear frames, circular frames with wire fixation and hybrid frames with circular wire and linear pin components. This case series reports the use of linear pin and arch pin component frames or frames with two arch components to acutely address deformity and normalise functional axes.

MATERIALS AND METHODS
Fifteen antebrachii (11 dogs) were operated for growth disturbance. Dogs with significant limb length discrepancy were excluded from the study. All patients were operated in sternal recumbency. Acute realignment of the radial segments was referenced from the transverse plane of the humero-radial joint for frontal, sagittal, rotational and translational components. In all cases a single transverse osteotomy was performed at the apex of deformity of the distal radius, with an ulnar osteotomy. Nine limbs were corrected using 1/3 ring arches and linear frame components and six limbs with two 1/3 ring arch frame components (Linear-Arch-Pin-Frame, LAPF and Double-Arch-Pin-Frame, DAPF respectively). Pin bone fixation was employed for all cases with a minimum of three pins per frame component. Attachment of divergent pins to a single arch was facilitated by applying half pin fixation bolts to either side of the arches, applying washers beneath half pin fixation bolts, or applying half pin fixation bolts to 1 or 2-hole posts elevated from the ring. Frames were applied proximal to the distal radial growth plate if still open. For LAPF the rod was attached to the arch using spherical nuts and washers, half-pin fixation bolts or two-hole post stand-offs. For DAPF, the arches were locked relative to each other using half pin fixation bolts placed on 1 or 2-hole posts which allowed three dimensional manipulation of the segments. Physical therapy was employed in all cases. Orthogonal pre- and post-operative radiographs of the operated limb and the contralateral limb when present were use to determine the Frontal (FPA) and sagittal plane (SPA) anatomic axes. Function and cosmesis were assessed pre- and post-operatively for all cases.
RESULTS
Mean age was 9.2 months (range 5-12 months). Mean weight was 21.1kg (range 4.7 – 58kg). Frame removal was accomplished for all cases by 7.5 weeks (range 5-7.5 weeks). Lameness or pain on manipulation of carpus or elbow through a normal range of movement was not evident for any patient by 10 weeks after frame removal. Radiographic assessment revealed correction of rotational deformity in both frontal and sagittal planes for all cases but less satisfactorily so for LAPF than DAPF. For 15 radii reviewed, the change in FPA (t=2.60, p=0.023) and SPA (t=4.52, p=0.001) following surgery was significant (paired t-test). FPA was corrected or improved in 10/15 dogs (66%); SPA was corrected in 12/15 dogs (80%). Pre-operative FPA range was 40-2° and post-operative 18–3°. Pre-operative SPA was 34–9°; post-operative 10-2°. Correction of radial procurvatum was less successful and minor residual translational deformity was evident in 7 of 15 antebrachii. Preoperatively all dogs had a fair or poor level of function. Postoperatively, all achieved good function and 8 of 15 were deemed functionally normal. Preoperative cosmesis was graded fair or poor and post-operatively all dogs achieved good cosmesis. One dog with bilateral surgery is yet to reach final follow-up evaluation.

DISCUSSION/CONCLUSION
The foci of radial deformities in this study were close to the radio-carpal joint or distal radial physis, leaving little space for implant placement. Pins divergent off frame arches allow maximum bone purchase and avoid growth plates. Half-pin fixation bolts mounted on arches allow complete freedom of movement in three dimensions and are a significant departure from conventional methodologies dependant on pre-operative planning and/or trigonometric calculations. Pin constructs require less technical expertise and less time for application than wire-circular frames. The technique depends on identification of the major apex of deformity and correction referenced off the frontal plane of the humero-radial joint. LAPF constructs allow less scope for three-dimensional correction, are more difficult to successfully apply and achieve less desirable functional and cosmetic results than DAPF constructs. DAPF constructs more readily facilitate correction of rotational deformity than dome osteotomies and obviate iatrogenic juxta-articular segmental translation that can occur with dome and cuneiform osteotomies. Pins placed in the cranial aspect of the distal radial segment allowed manipulation to ameliorate cranial bowing of the radius, which was difficult to address due to flexure contracture but was better facilitated by DAPF. The measurement of FPA from frontal plane radiographs in patients affected by rotational deformity is subjective and potentially inaccurate; in the absence of carpal valgus, rotation only was corrected and hence FPA would not be expected to change. Standard FPA and SPA ranges for clinically normal dogs of the breeds described in this case series have not been established and the contralateral limb is often similarly affected, therefore precluding relevant comparison. Pre-operative SPA values for this series were within previously published normals (8-35°) therefore it may not be necessary to address SPA values to achieve satisfactory functional outcomes. Breed variation and measurement technique could potentially affect FPA and SPA values hence their validity as a measure is questionable.

Residual procurvatum and translational deformities were better tolerated than rotational or valgus deformities in this study population and have had no observable effect in terms of pain or lameness. It could be argued that procurvatum and translational deformities are intrinsic to chondrodystrophic breeds and do not justify complex corrective planning. Linear distraction could be applied if necessary following acute angular correction by appropriate application of motors. Visual and radiographic assessment of functional and cosmetic outcomes for these patients was comparable to other methods published. Numbers of cases are small in this series and wider application of DAPF constructs concomitant with assessment of breed normals for procurvatum and translation of the antebrachium are warranted. Information regarding the presence of osteoarthritis at initial surgery and the impact of surgical intervention on the long term development of osteoarthritis would be useful to identify this technique as superior to others.
MATERIALS AND METHODS: Thirteen antebrachii of nine dogs underwent surgical correction of joint axes alignment. Rotational deformities in all cases precluded application of CORA methodology for surgical planning. Nine limbs were affected by uniapical deformities and four by biapical deformities. All patients were operated in sternal recumbence. A non-focal TDO of the radius at the point of maximum deformity and a bi-oblique caudo-latero-proximal to cranio-medio-distal osteotomy of the ulna at the junction of the proximal and mid thirds of radial length were performed. All osteotomies were made with 12 or 18mm Sphero™ Domesaw™ blades (Matrix Orthopedics Inc., Twin Falls, ID) attached to a reciprocating saw (Whittmore Enterprises Inc. Cucamonga, CA). Two 1.0 mm Kirschner wires or two 1.5-2mm negative profile half-pins were placed parallel to the frontal joint axes of the elbow and carpus and close to the respective joints to serve as reference anchors to correct for varus/valgus, procurvatum/recurvatum and rotational deformities. In all cases the transcondylar axis of the distal humerus and the transverse frontal plane axis of the radio-carpal joints were arbiters of alignment with repeated flexion and extension of the elbow and carpus. Three fixation methodologies were employed: external skeletal fixation (IMEX™ inc., Longview TX) (10 limbs), Compact UniLock™ plates (Synthes, Paoli, PA) plus K-wires (1 limb), and SOP™ plates (Orthomed, Huddersfield, UK) plus K-wires (2 limbs). Where ESF was employed, two arches and three to four divergent half pins were applied to each segment using safe corridors and segments were rotated relative to each other using multidirectional hinges, then locked using a cross-over connecting bar (Double arch pin poly-directional external realignment, DAPPER). For plate fixation, the segments were aligned and a K-wire placed for stabilization before application of plates and screws. Due to excessive valgus and procurvatum, a cranio-medial dome-wedge osteotomy was performed for two cases to improve bone contact. Wedges were morcelised and used as autogenous bone graft. Contact between proximal and distal bone segments was assessed intra-operatively and radiographically post-operatively. All cases were followed until osseous union and lameness resolution. Radiographic measures of sagittal and frontal joint axes, functional outcome and cosmesis were recorded.

RESULTS: Correction of joint axes misalignment and rotation deformities were uneventfully performed in all limbs. Humero-ulnar incongruity was addressed in all cases by ulnar osteotomy. Residual translational deformities were apparent in the frontal plane for three limbs (mean 12.8%, SD 24%, range 0-64%) and in the sagittal plane for two limbs (mean 9%, SD 19%, range 0-50%), but were not deemed clinically relevant, even in cases of biapical deformity. Bone contact was sufficient for uneventful osteotomy healing in all cases. Mean time to bone healing was 2.4 months (SD 0.8 months, range 2-3 months). Seven owners graded functional and cosmetic outcome as excellent and two graded outcome as good. Pain or lameness was not observed for any case after osseous healing. Post-operative radiographic measure of varus/valgus frontal plane joint alignment was mean 12.4° (SD 8.8°, range 0°-28°) and of cranial/caudal sagittal plane joint alignment was 18.4° (SD 11.5°, range 2°-40°), which was within range of the control group in a previous study.

DISCUSSION: The ACA was not centered on the CORA in any of the cases as significant rotational deformities did not allow for valid CORA measurements to be performed preoperatively. Correction for valgus, procurvatum and rotation were addressed via a single osteotomy and in cases affected by biapical deformities, translation was unavoidable, but functional and cosmetic results were satisfactory. Adequate bone contact between proximal and distal segments was achieved whilst the dome geometry allowed segmental manipulation around more than one axis. CT scan and multiple osteotomies should be performed if translational deformities are to be avoided, but for uniapical deformities results comparable with existing techniques can readily be obtained with TDO. Results are encouraging, but further investigation and mensuration of geometrical alignment consequences of TDO is warranted to guide clinical
recommendations.

REFERENCES

Surgery Chapter