Online Supplementary Material to:

Complex angular and torsional deformities (distal femoral malunions)

Preoperative planning using stereolithography and surgical correction with locking plate fixation in four dogs

Michael D. DeTora; Randy J. Boudrieau

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Appendix I

In order to determine the varus/valgus angulation, any torsional deformity was corrected first: either the center of rotation and angulation (CORA) close to the stifle joint (above the sulcus) in uniapical deformities, or at the proximal CORA in bi-apical deformities (1). Varus/valgus determination/correction was then independently assessed (at the distal CORA in bi-apical deformities), but also in combination with pro-/recurvatum assessment/correction at this same level.

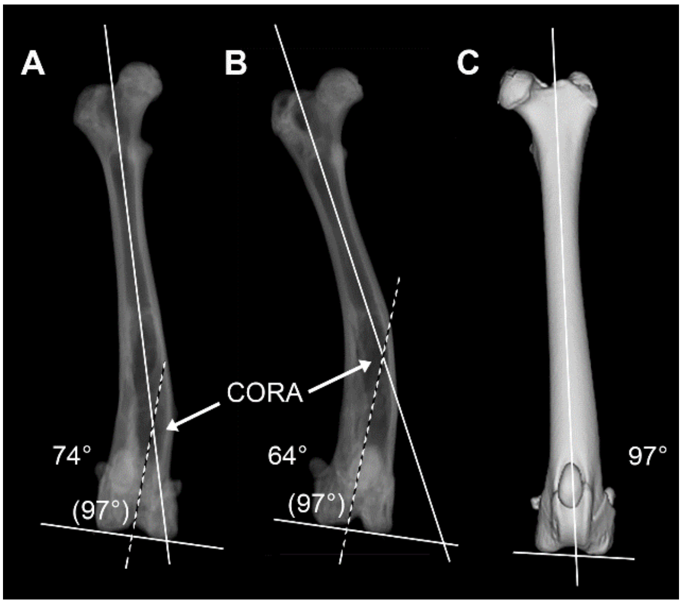

Figure 1 - 3D reconstruction of the femurs (limb 5): Because of the torsional deformity, either the distal femur is oriented in the frontal plane (A), or the proximal femur is appropriately oriented (B).

As is observed in the 3D reconstructions, depending on the orientation and the limb positioning, the CORA is at different levels and different magnitudes (74° vs. 64°, respectively). Therefore, the amount of correction in this case has a 10° variation as compared to the normal femur (C), of 23°or 30°.

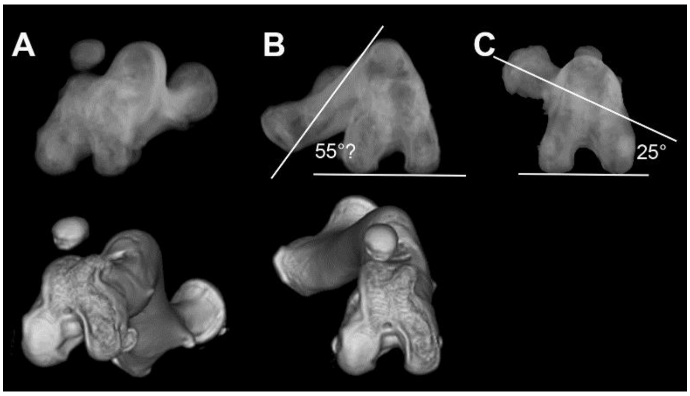

Figure 2 - 3D reconstruction of the femurs (limb 5): Similarly, positioning of the axial view of the femur also cannot realistically assess the anteversion of the femoral head and neck. In (A) and (B), it is not possible to determine the angle of the femoral head/neck (radiographic rendering above and volume rendering below); compare to the normal opposite limb (C).

In order to assess the magnitude of these deformities, and simultaneously select a known landmark that could be recognized at the time of the definitive surgical procedure, 1.6 mm Kirschner wires (K-wires) were placed in the SLA biomodels in the frontal and sagittal planes above and below the deformities as guidewires (2). These were initially placed starting distally, parallel to the distal femoral condyles in the frontal plane. Subsequent guide wire placement was performed perpendicular to the femur (just above the sulcus) in the [bone's] sagittal plane; positioning was assessed by comparison to the opposite [normal] femur to ensure appropriate procurvatum. Guide wires in the proximal femur were similarly placed in the frontal and sagittal planes using the opposite unaffected femur as guidance. Orientation of these wires was then recorded (angulation and rotation) relative to each other such that after placement of the 1st guide wire in the patient, these positions could then be similarly reproduced at surgery.

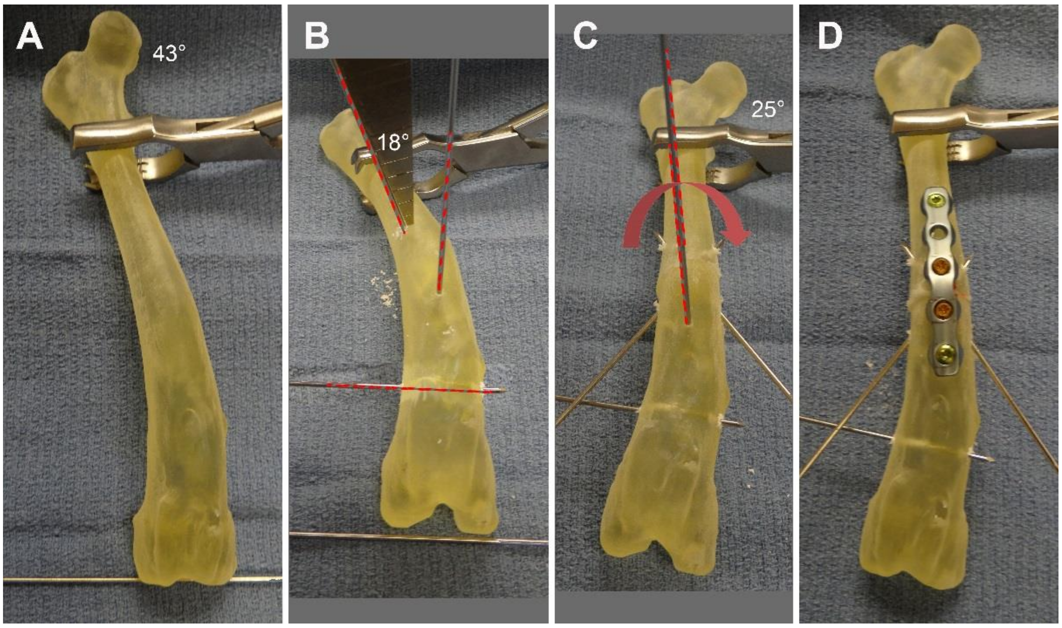

Figure 3 - Biomodel (limb 5) rehearsal surgery: Craniocaudal view of the biomodel centred on the femoral condyle (A); a biapical deformity is present: primarily torsion proximally and valgus distally; from gross evaluation of the model, it is determined that there is 43° of anteversion of the femoral head/neck (note that normal anteversion [see Figure 2 C] is 25°, or a torsional deformity of 18°). A K-wire orients the distal aspect of the femoral condyles parallel to the frontal plane of this bone. A parallel K-wire is placed into the distal femur just below the distal angulation (B); proximal to the level of this distal deformity, another K-wire is placed perpendicular to the first, parallel to the sagittal plane, and finally another K-wire is placed into the cranial femur at an angle of 18°. A transverse osteotomy is placed perpendicular to the proximal two K-wires and the proximal femur is rotated such that both proximal K-wires are parallel (C); two crossed K-wires traverse the osteotomy so as to temporarily stabilize the proximal correction. A 5-hole ALPS 10 is placed (in compression) to span this osteotomy on the cranial femoral surface (D).

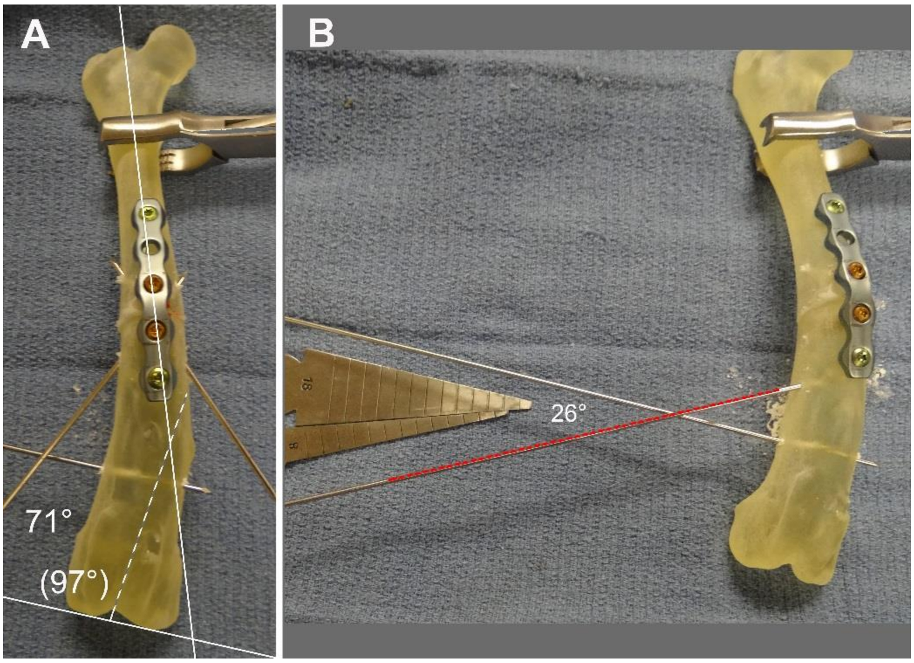

Figure 4 - At this point all rotational corrections have been made, and the CORA of the distal angular limb deformity can now be accurately determined (A). The aLDFA is 71°, as compared to the normal value of the opposite femur of 97°. Therefore, a 26° valgus deformity is present in the frontal plane (note that the photograph does not show the recurvatum correction); a 2nd Kirschner wire (red line) is placed in the frontal plane proximal to the CORA of this distal deformity at a 26° angle (B).

Osteotomies were performed on the SLA biomodels at [or close to] the respective CORA(s) based upon the measured angles of the deformities and oriented with the guide wire positioning; in addition, the osteotomy corrections were performed parallel to the respective guide wires. In bi-apical deformities, the proximal deformity was corrected first (transverse or closing wedge osteotomy), which also addressed the torsional deformities in these cases. The distal femoral osteotomy was performed immediately proximal to the femoral sulcus in all cases, either as a closing or opening wedge correction; in this locale, this resulted in the osteotomy performed proximal to the CORA when the latter was at the level of the joint. Once all osteotomies were completed, the correction brought the guide wires above/below each osteotomy parallel to each other in their respective [frontal/sagittal] planes. This positioning was then maintained temporarily with crossed K-wires; alternatively, in the two cases with an opening wedge osteotomy, a cranially applied 2-pin SK[a] external skeletal fixator (ESF) was used to maintain the gap. Any errors that became evident, which changed the preoperative plan were noted and corrected until a satisfactory alignment of the femur was obtained. The final fixation (plate[s]) was contoured to the surface of the SLA biomodel and applied with 1-2 standard bicortical screws per bone fragment. These pre-contoured plates were then removed and sterilized for the definitive surgical procedures.

[a] IMEX Veterinary, Longview, TX, USA

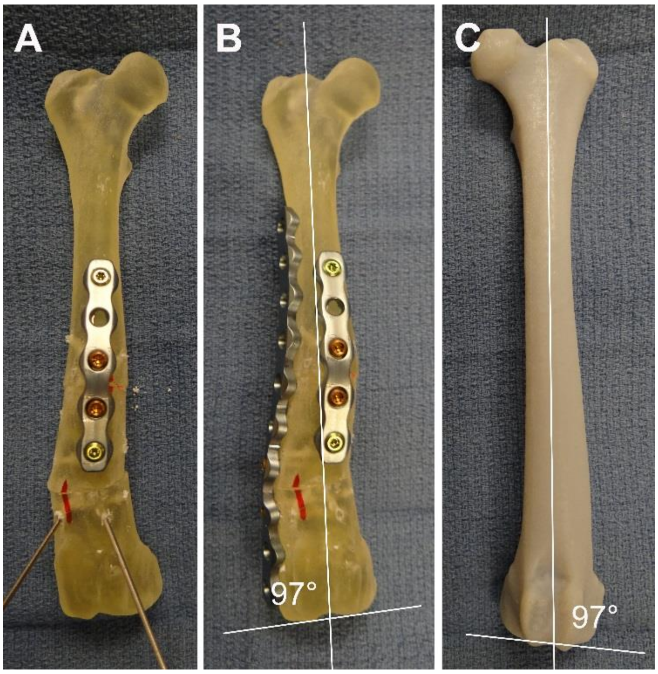

Figure 5 - After osteotomies are performed to the two respective K-wires parallel to the frontal plane (Figure 4B), the two ends of the bone are opposed and temporarily secured with two crossed K-wires (A). A 10-hole ALPS 10 is secured on the lateral bone surface in compression, and the two crossed K-wires removed (B). The aLDFA is measured (B) and compared with the opposite normal limb (C). {Note that the medial plate has not been placed (compare with Figure 5 in the manuscript: immediate postoperative radiographs of the affected femur).}

Photographs were obtained directly from these biomodels during each step of the procedure in order to retain a visual record of the stepwise process of the correction. Both the sequential photographic record from the rehearsal surgery on the SLA biomodels, and the corrected SLA biomodels, were available at the time of the definitive surgical procedure for reference.

References

1. Paley D. Principles of Deformity Correction. Berlin, Germany: Springer-Verlag; 2003.
2. Balfour RJ, Boudrieau RJ, Gores BR. T-plate fixation of distal radial closing wedge osteotomies for treatment of angular limb deformities in 18 dogs. Vet Surg 2000; 29: 207-217.

Appendix II

In accordance to the SLA biomodel preoperative planning, alignment guide wires (1.6 mm K-wires) were placed to provide an orientation and starting point for the respective corrective osteotomies. The positioning started with the 1st guide wire placed into the lateral aspect of the femoral metaphysis parallel to the distal extent of both femoral condyles in the frontal plane (identical to that performed with the SLA biomodel), then each subsequent guide wire was placed as indicated and noted from the rehearsal surgery on the SLA biomodel; thus, this 1st guide wire acted as the reference guide wire (guide wire positions intraoperatively required this orientation as the entire femur – most importantly the femoral head/neck [and version] – was not observed).

The osteotomies were again performed/repeated as with the SLA biomodel, and the guide wires brought parallel to each other. If, after completion of the osteotomies, the anatomic femoral axis was not aligned based upon the gross intraoperative assessment, gross visual assessment was used to further adjust the osteotomy(-ies), and was the final determinant of limb position.

As planned from the SLA biomodel rehearsal surgery, the opposing bone segments were temporarily secured with a Type I SK-ESF system[b] ± crossed K-wires to assist with reduction and alignment for the subsequent definitive plate fixation. In all dogs, a minimum of two standard cortical screws were first placed to secure (and compress) the pre-contoured plate to the bone's surface; minor adjustments to the plate contouring were made as necessary. Subsequently, locking monocortical screws were placed into each segment of bone on either side of the osteotomy.

[b] IMEX Veterinary Inc., Longview, TX, USA

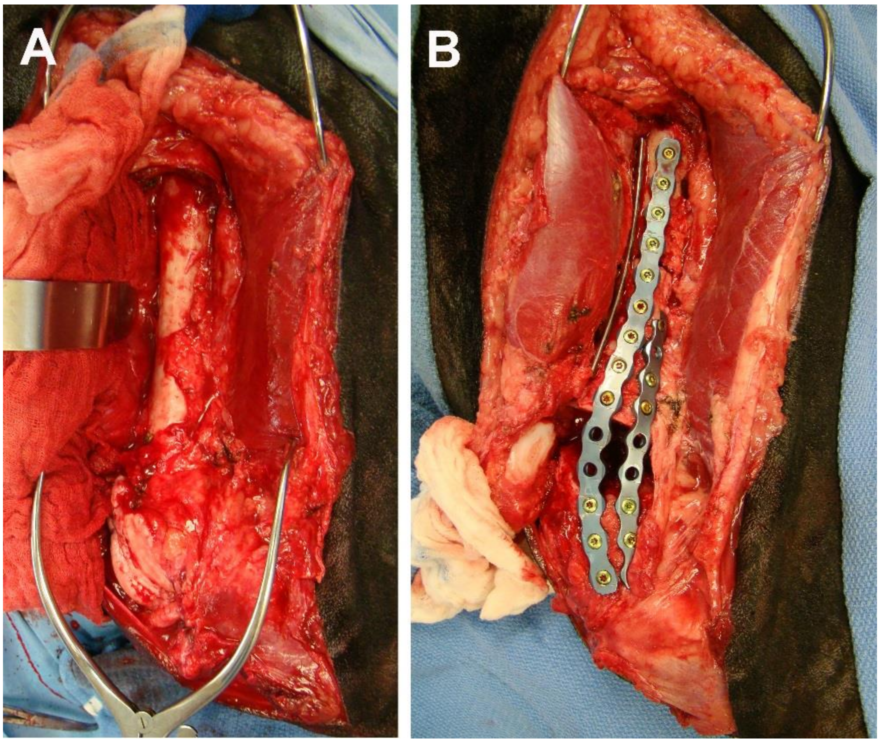

Figure 6 - Intra-operative gross photographs of limb 4: Lateral approach to the femur with osteotomy of the tibial tuberosity in order to expose the entire distal femur (A). After correction of the biapical deformity: a cranial 8-hole LC-DCP (compression) can be seen on the cranial bone surface to correct the 15°of valgus and 15° of torsion proximally (B). In addition, 33° of valgus and 23°of recurvatum has been corrected distally with a lateral and cranial opening wedge osteotomy; the lateral aspect of the femur was bridged with a 14-hole ALPS 11 cranially and a 9-hole ALPS 10 caudally. {Not observed is the medial surface of the femur that was bridged with a 9-hole ALPS 11 cranially and an 8-hole ALPS 10 caudally. {The observed defect was filled with 6 ml of Osteo-Allograft (fine mix).}

Definitive internal fixation of the proximal femoral corrections (in bi-apical deformities) was performed with compression plate fixation[c]; distal femoral corrections were performed with bilateral (opposite) medial and lateral ALPS plates as either an opening or closing wedge osteotomy. In cases in which an opening wedge osteotomy was performed, a commercially available allograft[d] (fine mix: combination of corticocancellous chips sieved to <2.5-mm. plus demineralized bone matrix) was placed to fill the defect.

[c] ALPS: Kyon Pharma, Inc., Boston, MA, USA; **or** LC-DCP®: DePuy Synthes® Vet, West Chester, PA, USA
[d] Osteo-Allograft™ (fine mix: combination of corticocancellous chips sieved to <2.5-mm. plus demineralized bone matrix): Veterinary Transplant Services, Kent, WA, USA

Appendix III

Telephone Questionnaire (long-term follow-up)

Please answer the following questions by choosing between 1-10 where appropriate between the two extremes (the far left and far right of each line representing 1 and 10, respectively) or comment where applicable.

1. What was your dog's exercise tolerance (ability to go for walks without stopping or tiring) preoperatively?

   ____

   1 (Struggles on short walks) 10 (Copes well with long walks)

2. What is your dog's exercise tolerance (ability to go for walks without stopping or tiring) postoperatively?

   ____

   1 (Struggles on short walks) 10 (Copes well with long walks)

3. How often does your dog indicate lameness when walking preoperatively?

   ____

   1 (Always) 10 (Never)

4. How often does your dog indicate lameness when walking postoperatively?

   ____

   1 (Always) 10 (Never)

5. What is your dog's current lameness score?

   ____

   1 (Always demonstrates signs) 10 (Never shows lameness)

6. How would you grade the success of the operation on the right leg? (N/A)

   ____

   1 (Poor) 10 (Excellent)

7. How would you grade the success of the operation on the left leg? (N/A)

   ____

   1 (Poor) 10 (Excellent)

8. Would you have this operation done again in the same circumstances?

   ____

   1 (Never) 10 (Definitely)

9. Did you seek veterinary care from any other facility regarding this problem?

10. Did you pursue physical therapy at a physical therapy facility? Any further comments?