Three-dimensional computer-assisted corrective osteotomy with a patient-specific surgical guide for an antebrachial limb deformity in two dogs

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Summary

We describe patient-specific surgical guide prototyping and surgical treatment of a complex antebrachial deformity in two skeletally mature dogs presented with chronic lameness. Computer-assisted surgery was elected to increase accuracy in the correction of the complex deformity.
Radiographs and computed tomography (CT) scans revealed a biplane deformity with valgus, procurvatum and external torsion of the right radius in both cases. The pre-surgical planning started from the quantification of the angular deformity, followed by computer simulated correction and to end up with a rehearsal surgery on 3D printed bone models. During the surgery, the custom-made osteotomy guides closely fitted the bone, allowing for a precise corrective osteotomy, that was stabilized with two locking plates. Postoperative radiographs showed the successful correction of the deformity. Eight and 12 weeks postoperative follow up examinations showed improved lameness, weight-bearing and progression of bone healing in both dogs.
Patient-specific surgical guides allowed for a satisfactory correction of the antebrachial deformity. Additional benefits of using customized surgical devices include standardization and reduced surgical time.

Key words: Bone deformity, computer-assisted surgery, dogs, patient specific surgical guides, rehearsal surgery

Dreidimensionale computerunterstützte Korrekturosteotomie mit einer patientenspezifischen chirurgischen Schablone bei zwei Hunden mit antebrachiellen Deformitäten

Der vorliegende Fallbericht beschreibt eine Korrekturosteotomie mit Hilfe einer patientenspezifischen chirurgischen Schablone bei zwei ausgewachsenen Hunden mit chronischer Lahmheit. Aufgrund der Komplexität der Unterarmdeformität wurde eine computerassistierte Chirurgie gewählt. Sowohl die Röntgenbilder als auch die Computertomographie zeigten biplanare Deformitäten mit einer Valgus, Prokurvatum und Aussenrotation Fehlstellung des rechten Radius. Die präoperative Planung beinhaltete die Quantifizierung der Deformität, die Computersimulation der Korrekturosteotomie und die Durchführung der Operation an 3D gedruckten Knochenmodellen. Die spezialangefertigten Osteotomie-Schablonen wiesen intraoperativ eine akkurate Knochenanpassung auf, welche präzise Korrekturosteotomien mittels jeweils zwei winkelstabilen Platten erlaubten. Die postoperativen Röntgenbilder zeigten in beiden Fällen eine gelungene Korrektur der vorangegangenen Deformitäten. Die klinischen und röntgenologischen Kontrollen nach 8 und 12 Wochen wiesen eine abnehmende Lahmheit, bessere Gewichtsbelastung und progressive Knochenheilung bei beiden Hunden nach. Die Patientenspezifischen chirurgischen Schablonen erlaubten akkurate Osteotomien und Korrekturen der Unterarmdeformitäten. Ein zusätzlicher Nutzen dieser Methode ist eine mögliche Standardisierung und eine Verkürzung der Operationszeit.

Schlüsselwörter: Knochendeformation, Computerassistierte Chirurgie, Hund, patientenspezifische chirurgische Guides, Testoperation

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Introduction

Bone deformities of the antebrachium represent the most frequent form of angular deformity in dogs[7] and often need corrective osteotomy to be treated appropriately.[6,15] To achieve this goal, an accurate study of the bone alterations based on center of rotation of angulation (CORA) methodology is imperative.[15] Preoperative planning for antebrachial deformity has been described based on orthogonal radiographs.[3,6] However, advancements within the orthopedic field have introduced three-dimensional (3D) imaging techniques such as computed tomography (CT)[14] and computer-aided-design (CAD) software[8,16] to enhance visualization of bone models. The acceptance of computed-based technology has strongly encouraged the customization and surgical use of 3D printed guides to aid surgeons intraoperatively.[1]

The present case report describes the design, prototyping and surgical application of 3D custom-made guides, which were used as computer-assisted devices to treat a biplane bone deformity of the antebrachium in two dogs.

Case report

Two castrated male dogs were referred to the Small Animal Hospital of the University of Zurich for chronic right front limb lameness.

Case 1 was a 7 years-old, mixed-breed dog, weighing 19.1 kg. On visual examination, the dog exhibited a 2/4° right front lameness. Radial procurvatum, valgus and external torsion of the distal right front limb were visible. At physical palpation, moderate atrophy of the antebrachial muscles, mild reduction of the range of motion (ROM) of the right elbow and painful carpal

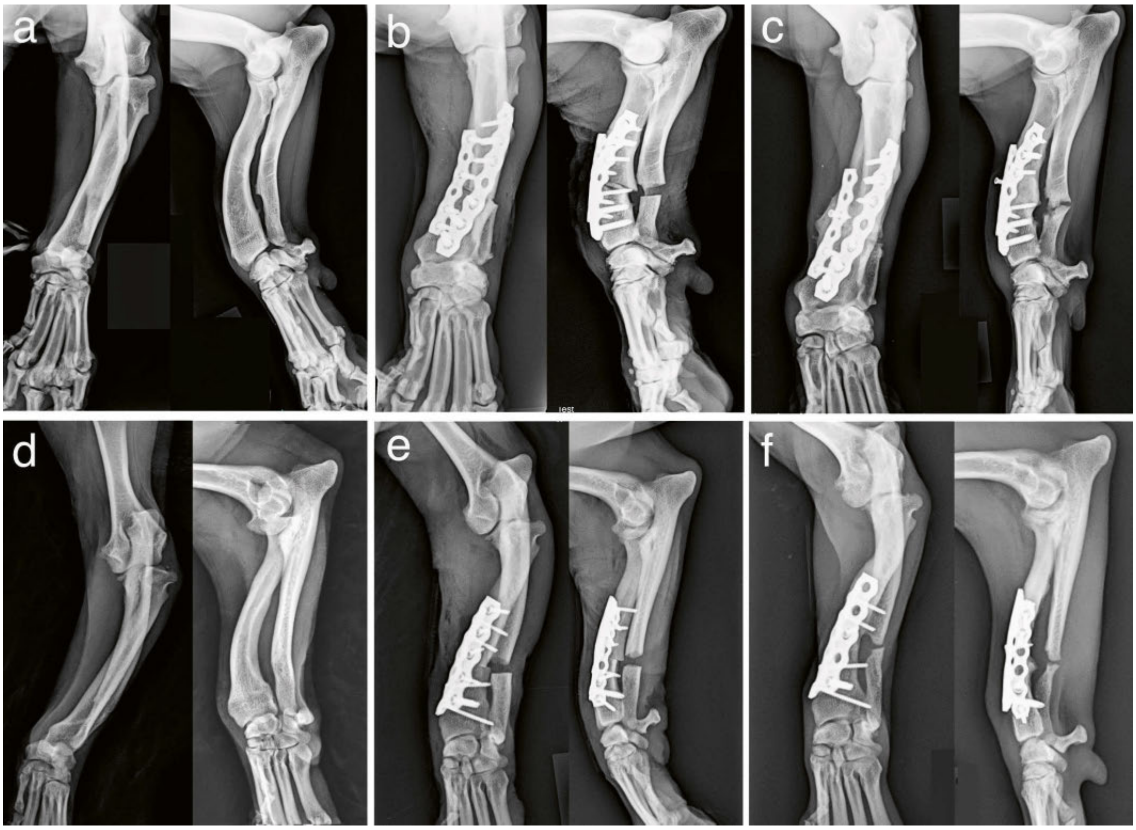

Fig. 1: Orthogonal radiographic studies of a 7 years-old, mixed-breed dog (case 1, upper line) and 3 years-old Shih T (case 2, lower line). Craniocaudal and mediolateral radiographic projections showing a biplane antebrachial bone deformity (a and d). On the craniocaudal projection, the presence of a valgus deformity was observed. A severe lateral subluxation of the radius head was also noticed in case 2 (d). A cranial bowing of the radius and a distal antebrachial torsion were detected on the mediolateral projection. Images (b and e) depict immediate postoperative radiographs. The craniocaudal and mediolateral projections show the correction of the radius valgus and procurvatum as well as the presence of an ulnar ostectomy. A double plating technique with hybrid locking implants was used. Images (c) and (f) show the radiographic recheck at12-weeks. A complete bone healing at the level of radius osteotomy was detected. On image (c) a loosening of the proximal locking screw of the smaller plate (c) was detected. Another proximal locking screw of the same implant was previously removed 8-weeks postsurgical. Image (f) shows that 3 screws were removed from the craniolateral plate following the detection of an increased radiolucency close to screws.

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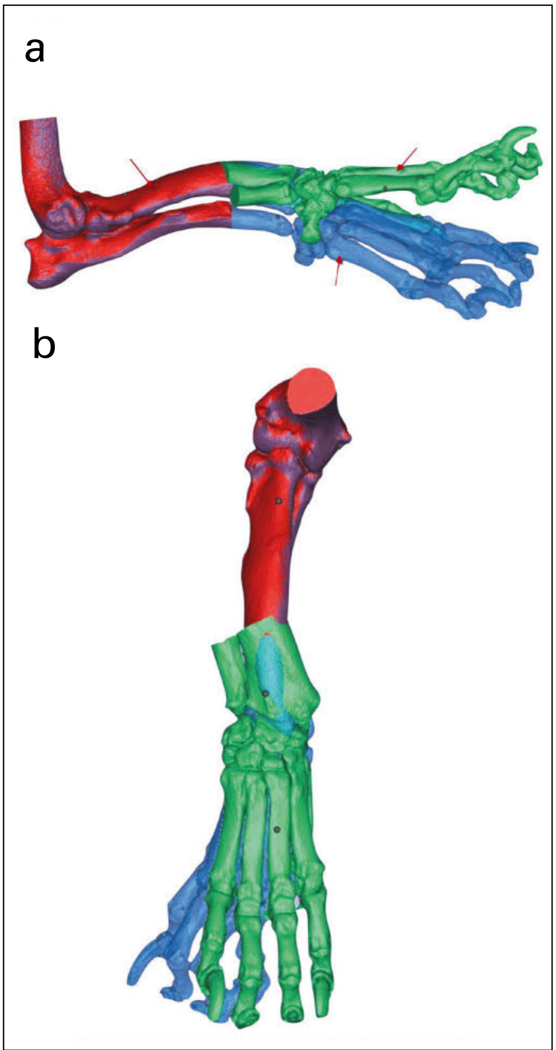

Fig. 2: Computer assisted preoperative planning case 1. A closing bone wedge was created in the bone model to correct frontal and sagittal deformities. The ostectomized bones were manipulated to reach a new alignment (red and green bone models). The post-corrective antebrachial alignment was compared to the pre-corrective alignment (blue and purple bone models) by means of mirror image function. Red arrows indicate (a) the translation of the distal antebrachium on the sagittal plane.

flexion were found. An orthogonal radiographic study (Fig. 1a), followed by a CT examination of the front limbs, showed mild incongruence of the right elbow joint, shortening of the ulna, proximal displacement of the radial styloid process, valgus and torsional deformities in the right antebrachium.

Case 2 was a 3 years-old Shih Tzu of 3 kg. On visual examination, a 2/4° front right lameness was noted along with the presence of radial procurvatum, valgus and external torsion of the paw. The physical examination revealed mild atrophy of antebrachial musculature with diminished and painful ROM of the elbow. Radiographic and tomographic findings (Fig. 1d) confirmed the clinical findings, showing an elbow incongruence with severe shortening of the ulna, presence of a large intra-articular fragment compatible with a fragmentation of the medial coronoid process, radial head subluxation and flattening of the ulnar trochlear notch.

Computer Assisted Preoperative Planning

The preoperative planning was carried out with the assistance of an engineering company (IRPD, St. Gallen, Switzerland) and consisted of four steps:

1- The proximal and distal radial anatomical angles were measured on craniocaudal and mediolateral radiographs of the affected radius. On the craniocaudal view, the anatomic medial proximal radius angle (aMPRA) measured 69° (case 1) and 53° (case 2), while the lateral distal radius angle (aLDRA) was 78° and 76° respectively. On mediolateral view, the anatomic proximal caudal radius angle (aCdPRA) measured 99° (case 1) and 122° (case 2); while the distal caudal radius angles (aCdDRA) was 58° and 75° respectively. The magnitude of CORA was for case 1: 28° valgus and 34° procurvatum and for case 2: 15° valgus and 31° procurvatum.

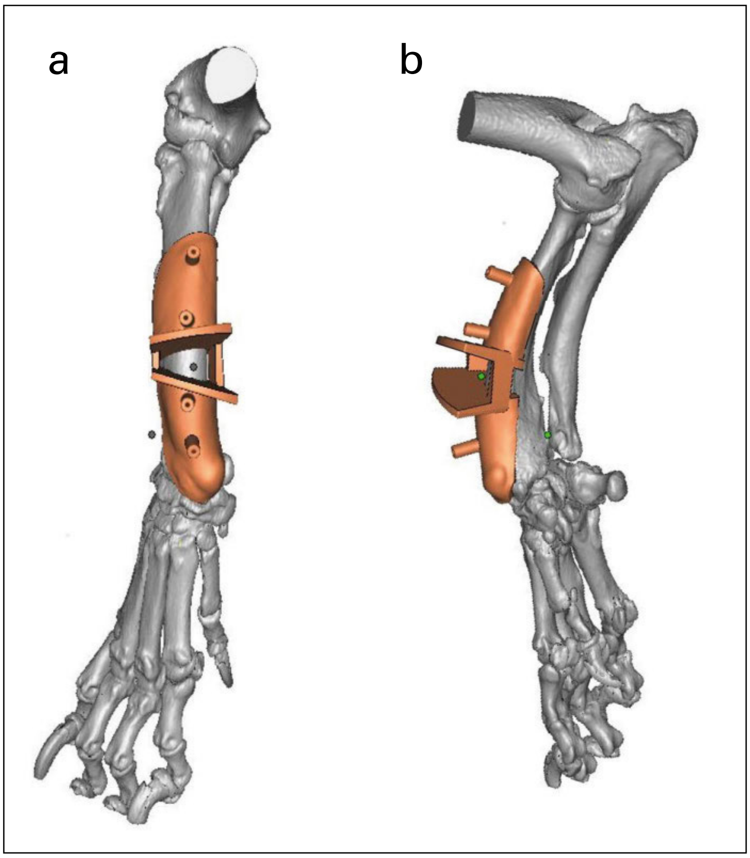

Fig. 3: Three-dimensional printed patient-specific osteotomy guides case 1. Image (a) shows the temporary fixation of the osteotomy guide. Image (b) shows the design and simulated application of the osteotomy guide onto the radial surface. The distal medial edge of the osteotomy guide was planned to anatomically match the profile of the medial ridge of the radius groove.

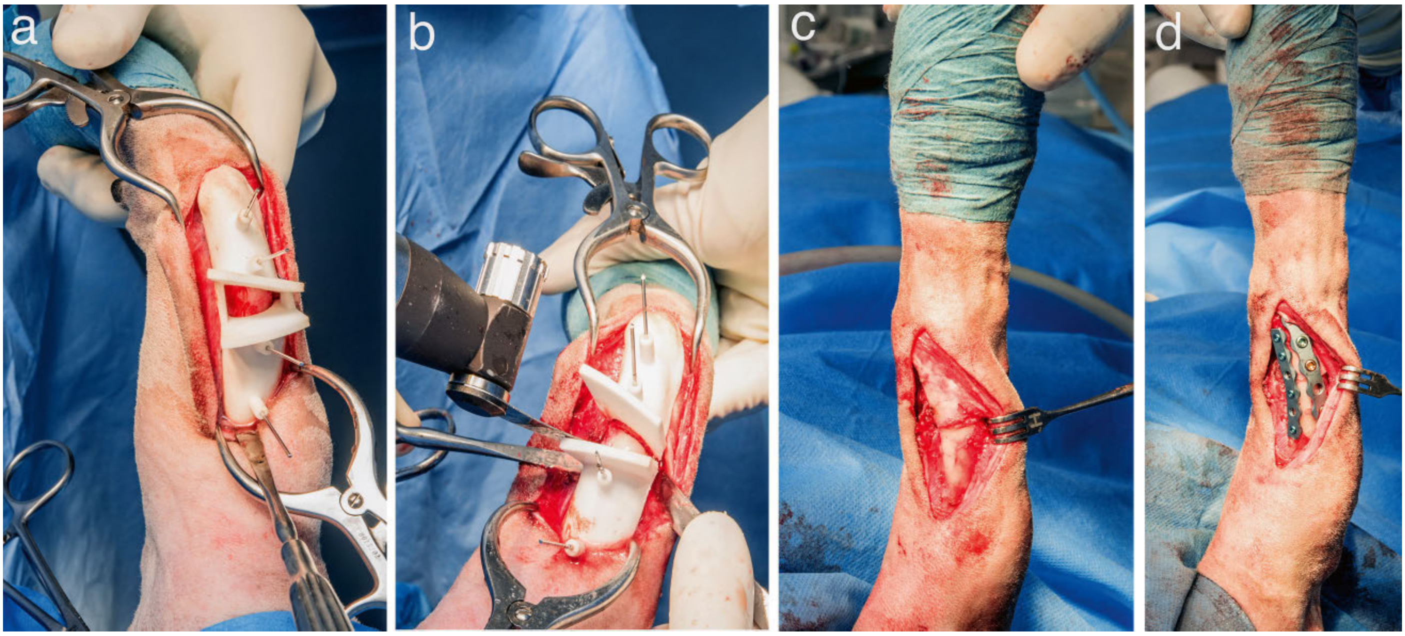

Fig. 4: Intraoperative images of a 7 years-old, mixed-breed dog (case 1). Temporary fixation of the osteotomy guide with four K-wires (a). Execution of the radius closing wedge ostectomy (b): the osteotomy guide slits support the drill blade and guide the osteotomy. Anatomical bone reduction: a new antebrachial alignment was achieved (c). Radial double plate fixation using pre-contoured locking implants (d).

2- The right antebrachium was segmented with a commercially available DICOM software (Osirix, Pixmeo, Switzerland) and a stereolithographic (STL) file was created to obtain a 3D surface bone model. The STL file was imported in a CAD software where it was elaborated. A computer-simulated correction was performed. A closing wedge was removed from the medial and cranial radial cortices, based on either the quantification of the deformity or the CORA location. The bones were then digitally aligned in a new position, reaching parallelism between proximal and distal joint reference lines (Fig. 2a,b). The new antebrachial positioning was compared to the starting bone alignment (mirror image function).

3- The osteotomy guide was set up on the basis of the quantification of the closing wedge and on the profile of the dorsal radius. This custom-made surgical device was designed to have two osteotomy slits functioning as plane guides: the angle of intersection of the two osteotomy slits was equivalent to the magnitude of the CORA. The printed guide included two holes with a co-planar orientation on both sides to temporary fix the guide on bone through K-wires (Fig. 3a,b).

4- The osteotomy guide was prototyped and manufactured in a true to real scale with a material that could be sterilized and shaped in surgery (Polyamid 12). Several bone models (Polylactic acid) of the affected antebrachia were 3D printed (Drukarka 3D, 3D Gence SP., Poland) to perform a rehearsal surgery. During the rehearsal corrective osteotomy, the fitting and shaping of the osteotomy guide on the radial cortex as well as the feasibility of deformity correction were checked. Locking plates (ALPS, Kyon, Zurich) were contoured to fix the bone fragments and then sterilized for the surgery.

Surgery

A cranial approach to the radius was performed, extending the skin incision from the radial diaphysis to the carpal joint. The custom-made osteotomy guide was positioned on the radius and temporarily fixed with four 1mm K-wires (Fig 4a). A closing wedge osteotomy of the radius was executed with an oscillating saw by aligning the saw blade with the osteotomy slits (Fig. 4b). A lateral approach to the ulna was made through a skin incision from the ulnar styloid to the midshaft. An ulnar ostectomy was performed. The osteotomy guide was removed, and external torsion was corrected intraoperatively aligning the carpus to the elbow. The correction of the valgus and procurvatum deformities was achieved by aligning the radial fragments with bone reduction forceps (Fig. 4c). The pre-contoured locking plates (ALPS 8 and 6.5) were fixed on the craniolateral and medial cortex of the radius using locking and cortical screws (Fig. 4d). To promote bone healing, autogenous cancellous bone graft was collected from the proximal humerus and packed around the radius osteotomy and ulnar gap. The surgical wound was closed routinely.

Orthogonal postoperative radiographs showed a correct implant positioning and an improved antebrachial alignment (Fig. 1b, e). Cage rest was recommended for 6-8 weeks. Activity was restricted to ten minutes walking, 2-3 times per day and gradually increased until complete bone healing. Radiographs rechecks were planned at 4, 8, and 12 weeks.

Follow-up examination

Case 1 significantly had improved after 4-week. A minimal lameness (1/4°) along with mild painful carpal palpation and reduced carpal ROM in flexion were noticed. Recheck radiographs showed loosening of the proximal locking screw of the cranial-medial plate. Thus the screw was removed. After 8-weeks weight bearing of the operated limb had improved and the radiographs showed a progressive new bone formation at the osteotomy sites (Fig.1 c). The osteotomy site had completely healed after 12 weeks. At this time a second proximal locking screw of the craniomedial plate was loose and therefore removed. One year postsurgically the dog showed no lameness with an improved and pain free carpal ROM.

Case 2 had improved 4 weeks postsurgically, but still presented a 2/4° right front limb lameness and was moderately painful on elbow palpation. Radiographs showed an advanced healing of the radial osteotomy and a decreased radio-ulnar step with moderate osteophytosis in the cranial aspect of the radial head. The 8 and 12-weeks rechecks showed new bone formation with an increased radiopacity in the radius and solid new callus formation in the ulna gap. Mild radiolucency in the area of one distal and two proximal screws were noticed. Therefore these screws were removed (Fig.1 f). At the final 16-weeks postoperative check the dog exhibited a 1/4° right front limb lameness. On palpation an increased antebrachial muscular tone and a mild painful ROM of the right elbow were found.

Discussion

We found that the computer-assisted corrective osteotomy allowed a correction of the deformity with a simple intraoperative execution of the preoperative planning. The application of the osteotomy guides to the distal radius was facilitated by the profile adjusted to the true-sized bone model derived from CT images. As a result, no time was spent in manually finding the planned osteotomy site. We found that the custom-made osteotomy guides closely fitted the bone without extensive soft tissue dissection. Furthermore, neither use of additional joint-oriented K-wires nor fluoroscopy were needed. Both patients had a positive clinical outcome with an improved limb use. Despite the strong fixation provided by the double plate technique, we had some minor implant-related complications, which were easily managed and did not compromise the success of the surgeries. We opted for using a double plate fixation, based on the complex biplane nature of the deformity. In addition, the use of two smaller plates rather than a single large implant may decrease the impingement between implant and extensor tendons.

Advantages of computer-assisted surgical techniques involve both preoperative and intraoperative phases of corrective osteotomies. First, CAD software enables the user to manipulate the bone model, design bone wedges and detect the planes of the articular surfaces.[13] A mirror imaging function is available to superimpose the affected region on either the original alignment of the bone or the contralateral reference limb, enabling a precise deformity correction. Second, rehearsal surgeries could be performed on 3D printed bone models, allowing to test the guides before the surgery.[9,12] The rehearsal surgery was useful because we slightly modified the printed guides to improve the fitting on the radius and adjust the angle of the osteotomies. Additionally, we were able to pre-contour all the implants, without the need of intraoperative modifications and, thus, decreasing the surgical time. Third, performing a free-hand osteotomy may potentially lead to errors. The patient-specific osteotomy guides act as precise intraoperative localizers of the CORA and provide a controlled guidance during the osteotomy. Therefore, we may speculate that these devices could be helpful for surgeons who are at the initial learning curve for the treatment of such complex bone deformities.

The potential drawbacks of computer assisted surgery are the cost and the time required to plan and print the osteotomy guides. The time for performing the preoperative plan is mainly related to the type of CAD software used and the learning curve for correctly elaborate the 3D data. The cost is mostly associated with the stereolithography modelling and guide prototyping. When considering the cost-benefit of computer assisted surgery, animal with complex deformities may be the best candidates for these advanced techniques.

The correction of biplane antebrachial deformities requires a detailed planning to localize and quantify the malalignment and to limit the complication rate.[2,7] It may be not feasible to accurately evaluate such complex bone deformities neither with a 2D radiographic study nor CT.[4,10] Furthermore, as extensively demonstrated in human medicine (REF computer assisted vs free-hand), computer assisted-surgeries could be more accurate and faster than free-hand techniques when performing osteotomy[13] fracture fixation,[17] joint replacement surgery11 and vertebral screw placement as well.[5]

With regard to torsional correction, several papers reported the use of reduction guides, which allow for achieving a precise reduction of bone fragments.[9,10]

These devices are designed to have the proximal K-wire holes not aligned with the distal holes. As a result, a correction of a torsional deformity is achieved by aligning the K-wires after the completion of the osteotomy. In this study, we didn't diagnose a severe external torsion of the distal antebrachium and thus we opted for a visual alignment of the carpus to the elbow, before the final bone reduction. The use of joint-oriented K-wire could have been an efficient strategy for performing a more controlled correction of the torsional deformity. Alternatively, an external circular or hybrid fixator could have represented a useful surgical option for either osteotomy reduction or fixation of bone fragments.

In conclusion, we reported the prototyping and surgical application of patient-specific osteotomy guides, which allowed for a deformity correction that led to a successful clinical outcome. The reestablishment of a more physiological alignment of the antebrachium and carpus loading might limit the development of osteoarthritis in the medium-long term, thus decreasing chronic pain. Rehearsal surgeries and custom-made osteotomy guides represent favorable solutions for surgeons, who are challenged by the treatment of complex corrective osteotomies. In our experience, the surgically assisted correction of the angular limb deformity was straightforward compared to standard osteotomy and reduction technique.

Osteotomie corrective tridimensionnelle assistée par ordinateur avec un guide chirurgical spécifique au patient pour une déformité du membre anterieur chez deux chiens

Nous décrivons le prototypage d'une procédure chirurgicale spécifique au patient et le traitement chirurgical d'une déformation antébrachiale complexe chez deux chiens ayant atteint leur maturité squelettique et présentant une boiterie chronique. La chirurgie assistée par ordinateur a été choisie pour accroître la précision de la correction de la déformation complexe. Les radiographies et la tomodensitométrie (TDM) ont révélé une déformation dans deux plans avec valgus, procurvatum et torsion externe du radius droit dans les deux cas. La planification préopératoire a commencé par la quantification de la déformation angulaire, suivie par une correction simulée sur ordinateur et a abouti à une opération de répétition sur des modèles d'os imprimés en 3D. Pendant l'intervention, des guides d'ostéotomie sur mesure ont ajusté l'os de manière exacte, permettant ainsi une ostéotomie correctrice précise, stabilisée avec deux plaques de verrouillage. Les radiographies postopératoires ont montré la réussite de le correction de la déformation. Les examens de suivi postopératoires effectués à huit et douze semaines ont montré une amélioration de la boiterie et de la mise en charge ainsi que la progression de la cicatrisation des os chez les deux chiens. Les guides chirurgicaux spécifiques au patient ont permis une correction satisfaisante de la déformation antébrachiale. L'utilisation de matériel chirurgical personnalisé comporte d'autres avantages, tels que la standardisation et la réduction du temps de l'intervention chirurgicale.

Mots clés: Difformité osseuse, chirurgie assistée par ordinateur, chiens, guides chirurgicaux spécifiques au patient, chirurgie de répétition

Osteotomia correttiva tridimensionale assistita da computer con una guida chirurgica specifica al paziente per una deformità dell'arto antibrachiale in due cani.

In questo studio viene descritta un'osteotomia correttiva con l'aiuto di una guida chirurgica specifica al paziente e del trattamento chirurgico di una complessa deformità antibrachiale in due cani con scheletro adulto che presentano una zoppia cronica. Per aumentare la precisione nella correzione della complessa deformità, si è scelto di utilizzare la chirurgia assistita da computer. Sia le radiografie che la tomografia (CT) hanno rivelato delle deformazioni biplanari con valgo, deformità procurvata e torsione esterna del radio destro in entrambi i casi. La pianificazione preoperatoria comprendeva la quantificazione della deformità, la simulazione della correzione al computer e infine l'esecuzione di un intervento chirurgico su modelli ossei in 3D. Durante l'intervento, la guida osteotomica specifica al paziente si adattava con precisione all'osso, permettendo una precisa osteotomia correttiva stabilizzata da due stabili piastre. Le radiografie post operative mostravano la correzione della deformità effettuata con successo. I controlli postoperatori a otto e 12 settimane mostravano un miglioramento della zoppia, un miglior carico del peso e una progressiva guarigione ossea in entrambi i cani. Le guide chirurgiche specifiche al paziente hanno permesso delle osteotomie accurate e la correzione della deformità dell'arto antibrachiale. Un ulteriore vantaggio di questo metodo è una possibile standardizzazione e una riduzione dei tempi operativi.

Parole chiave: Deformità ossea, chirurgia assistita da computer, cani, guide chirurgiche specifiche al paziente, chirurgia test

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