Rapid prototyping to design a customized locking plate for pancarpal arthrodesis in a giant breed dog

M. Petazzoni¹; T. Nicetto²
¹Clinica Veterinaria Milano Sud, Peschiera Borromeo (Mi), Italy; ²Diagnostica Piccoli Animali, Zugliano (Vi), Italy

Keywords
Rapid prototyping, custom plate, pancarpal arthrodesis, locking plate, dog

Summary
This report describes the treatment of traumatic carpal hyperextension in a giant breed dog by pancarpal arthrodesis using a custom-made Fixin locking plate, created with the aid of a three-dimensional plastic model of the bones of the antebrachium produced by rapid prototyping technology. A three-year-old 104 kg male Mastiff dog was admitted for treatment of carpal hyperextension injury. After diagnosis of carpal instability, surgery was recommended. Computed tomography images were used to create a life-size three-dimensional plastic model of the forelimb. The model was used as the basis for constructing a customized 12-hole Fixin locking plate. The plate was used to attain successful pancarpal arthrodesis in the animal. Radiographic examination after 74 and 140 days revealed signs of osseous union of the arthrodesis. Further clinical and radiographic follow-up examination three years later did not reveal any changes in implant position or complications.

Case report
A three-year-old 104 kg male Mastiff dog was admitted for the complaint of severe (grade 3/4) right forelimb lameness. Twelve weeks previously the animal had fallen from a grooming table and had been severely lame since. On examination, hyperextension of the right carpus was evident (Figure 1); signs of pain were elicited on passive flexion and extension of the carpus. Orthogonal radiographs revealed signs of osteoarthritic changes on the dorsal surface of the base of the metacarpal bones (Figure 2). From mediolateral radiographic images in hyperflexion and hyperextension (Figure 2B) we determined that the maximum angles of flexion and extension of the carpus were 164° and 230° respectively. We diagnosed carpal hyperextension at the carpometacarpal joint and severe antebrachio-carpal instability. Pancarpal arthrodesis was recommended.

Introduction
In cases where it is not possible to restore the functionality of a joint, the surgical salvage procedure of arthrodesis is often used as an alternative to amputation (1). Arthrodesis of the carpals may be indicated in cases of osteoarthritis, articular fracture, chronic luxation, ligament lesions, hyperextension, and also developmental abnormalities of the antebrachio-carpal, middle carpal and carpal-metacarpal joints (1–8). Fusion of the middle carpal and carpal-metacarpal joints alone is possible if only these joints are affected, while pancarpal arthrodesis is generally performed if the antebrachio-carpal joint is involved (2).

Osteosynthesis techniques described for these types of surgery include application of a bone plate to the dorsal, medial, or palmar aspects of the carpus; cross-pinning; and transarticular linear or circular external skeletal fixation (1–3, 9–13). For large breed dogs, a dorsal plate with 3.5 mm screws is suggested (2). Double implants on the dorsal surface of the carpus may be necessary to achieve effective and stable arthrodesis in giant breed dogs (3).

Biomodels have been successfully used since the 1990s to help diagnose, plan and rehearse medical procedures on human patients (14). More recently three-dimensional models, created by rapid prototyping techniques, have been used for the preoperative planning of surgery to correct angular deformities in the limbs of dogs (14–15).

The present report describes the use of three-dimensional computer tomographic (CT) imaging and rapid prototype modelling to guide the manufacture of a custom plate with locking screws to achieve pancarpal arthrodesis in a giant breed dog (16).
On the same day, the dog was premedicated with methadone (0.2 mg/kg) and acepromazine (10 µg/kg). Anaesthesia was induced with propofol (3 mg/kg) and maintained with isofluorane (1.5%) in oxygen for CT using a helical CT scanner in single-slice mode. The dog was positioned in sternal recumbency with the right forelimb extended cranially allowing the radius, the carpal joint and the metacarpal bones to lie in neutral position. Transverse 1 mm slices were obtained beginning at the elbow joint and including the metacarpal-phalangeal joints. Images were obtained at zero degrees gantry tilt. Using the CT files (DICOM format), a rapid prototyping centre produced a three-dimensional model of the bones of the right antebrachium (Figure 3).

Screw positions were planned on the model (Figure 3). A Fixin locking plate was then designed and produced based on the model and the positions of the screw holes (Figure 3) (16). The plate, 23 cm long and 3 mm thick, was made of AISI type 316 LVM stainless steel; it had 12 threaded holes to accommodate 12 titanium-alloy screw-in bushings which in turn accepted 3 or 3.5 mm diameter self-tapping titanium alloy screws. The tapered head of each screw precisely fitted the internal tapered surface of each bushing, thereby locking the screw to the plate as it was screwed into the bone (16).

Surgery

Surgery was conducted under general anaesthesia with the patient in the sternal recumbency. A standard dorsal midline surgical approach from the mid-radius to the distal-metacarpal level was made, and the bones were exposed after a tourniquet had been applied (2, 17). The articular cartilage of the antebrachiocarpal, middle carpal, carpometacarpal and intercarpal joints was debrided using a high speed bur. cancellous bone, harvested from the ipsilateral proximal humerus, was packed into all joint spaces. Ten 3.5 mm screws and two 3 mm screws were used to fix the plate. Six 3.5 mm screws were used to fix the plate to the radius, the other six to attach the plate to the third and fourth metacarpal bones (Figure 4). The distal screws were fixed first to centre the plate holes over the third and fourth metacarpals. The two 3 mm screws were used in two plate holes as the surgeon noticed that the hole axes did not align perfectly with the centre of the underlying metacarpal bone. Cefazolin sodium (30 mg/Kg IV) was administered thirty minutes before surgery and then every hour till the end of the procedure. The wound was closed routinely.
would provide the greatest likelihood of achieving effective arthrodesis. The plate was designed with the aid of a full-scale model of the bones of the affected limb produced by rapid prototyping technology from CT images. The plate thus produced proved to be a perfect fit requiring no

Results

The patient was examined at 15 (when the sutures were removed), 30, 74, and 140 days, as well as at one, two, and three years after surgery. Fifteen and 30 days after surgery, lameness was difficult to observe and was not consistently apparent, and deep palpation of the carpal and metacarpal regions did not evoke a pain response. By 74 days, limping was absent, and palpation of the carpal and metacarpal regions did not evoke a pain response. By 74 days, limping was absent, and palpation of the carpal and metacarpal regions evoked no pain response; radiographs showed adequate radiographic healing

Discussion

In view of the patient's weight we considered that the use of a custom-made plate would provide the greatest likelihood of achieving effective arthrodesis. The plate was designed with the aid of a full-scale model of the bones of the affected limb produced by rapid prototyping technology from CT images. The plate thus produced proved to be a perfect fit requiring no

Postoperative management and outcome

Orthogonal radiographs were obtained immediately after surgery (Figure 4) to verify plate and screw position. The plate covered 55% of the length of the radius and 68% of the length of the third and fourth metacarpal bones. The administration of amoxicillin with clavulanic acid (20 mg/kg, orally, twice daily for 10 days), carprofen (2 mg/kg orally, twice daily for three weeks) and tramadol hydrochloride (2 mg/kg orally, twice daily for three weeks) was prescribed. A Robert Jones bandage was applied for three days to minimize postoperative swelling. The limb was not splinted during the postoperative period. The owner was instructed to confine the dog until radiographic signs of bone healing were evident. Confinement in a cage was suggested for eight weeks and in-door confinement for a further four weeks with 15 minute leash walks four times a day.

References

i Synulox: Pfizer, Latina, Italy
j Rimadyl: Pfizer, Latina, Italy
k Altadol: Formevet, Milano, Italy
intraoperative modification. Furthermore, flattening the flare of the distal radius slightly by removing a small portion of bone to avoid the need to double bend the plate was unnecessary in our case because the custom-made plate fitted the bone perfectly (2).

The angle between the distal and proximal parts of the plate – defining the angle of arthrodesis – was approximately six degrees, in line with the suggestion of White-lock and colleagues, but less than the 10° suggested by other authors (2, 18). White-lock and colleagues hypothesized that the smaller angle might reduce stress risers at the distal end of the plate by reducing the moment of weight-bearing forces at this point (18). The radial carpal bone was not used as a fixation point for the plate so that a plate hole in this location would not weaken the plate at the point where it was bent and bending forces were most concentrated.

We used a locking plate that is not pressed tightly against the bone surface when the screws are tightened and is not required to be perfectly contoured to the bone surfaces, but relies on purchase between the screws and the bone to achieve stability (16, 19, 20). The minimal contact of the plate against the bone surface reduces insult to the periosteum and its vascularization (19–24). However, the locked screws enter the bone at predetermined angles which cannot be changed intraoperatively unless the plate is twisted. The risk of fracture is increased if a screw is inserted into the metacarpal bone peripherally rather than centrally (18). Since two plate holes did not align perfectly with the centre of the underlying metacarpal bone, we used two smaller diameter screws to minimize the risk of a fracture. Apart from these, we were able to use 3.5 mm screws in the metacarpals, as they did not exceed 30% of bone diameter as advised (2, 16, 20). The pre-planning of screw positions and angles on the model can help overcome this limitation (▶Figure 3).

In our opinion, currently available commercial plates are not of adequate size and strength to provide sufficient stability for achieving effective arthrodesis in giant breed dogs. We could have used double implants on the dorsal surface of the carpus, which affords more strength and stability than a single plate. Another option was to use a broad pancarpal arthrodesis plate (CastLess plate) with staggered distal plate holes that allow the screws to engage both the third and fourth metacarpal bones (25). However the largest available CastLess plate is 140 mm long, of which 77 mm covers the radius, 28 mm the carpus, and 35 mm the metacarpals. Such a plate would have covered only 35% of the radius and 36% of the metacarpals in the present patient. In view of the extraordinary weight of our patient, we considered that such minimal coverage would have resulted in an unacceptably high risk of metacarpal bone fracture. It was recommended that a plate should cover over 50% of the metacarpal bones to ensure low risk of fracture (18).

The self-compressing load position of the screws in conventional plates allows the screws in the radius and metacarpals to compress all the joint levels. In our case, the locked position of the screws into the plate negated screw angulation and compression between bone fragments, thus interfragmentary bone compression was not achievable. Nevertheless the arthrodesis healed within the expected timing, probably due to good stability provided by the custom implant with locked technology (26).

Use of a short moulded palmar splint or cylinder cast has been recommended to protect the plate during healing (2, 5, 8, 10). Cast-associated soft-tissue injuries occurred in 63% of the patients in one recent retrospective study (27). However, the Fixin implant system provided sufficient support to allow healing of the pancarpal arthrodesis in this giant breed dog without additional external coaptation.

It has been proposed that the metacarpal bones are flexible enough to bend slightly during weight bearing, which may result in loosening of the distal screws since the plate is more rigid (2). The plate eventually may have to be removed because of screw loosening or irritation (2, 8). Three years after surgery, our patient did not show radiographic signs of screw loosening, and did not show clinical signs of soft tissue irritation. The locked plate we used may therefore have avoided or at least delayed screw loosening and soft tissue irritation, in part because it covered most of the length of the metacarpals and over half the length of the radius. Nevertheless, the bone sclerosis observed around some screws of the radius, and exostosis found on the dorsal surface of the distal extremities of the metacarpals, are indicative of force concentrations at these points. Lack of limping and signs of pain on palpation at one, two, and three-year check-ups suggested bone sclerosis and exostosis were not a clinical problem.

Conclusions

Use of rapid prototyping technology appears as a useful means of producing life-size three-dimensional plastic models of affected skeletal structures that in turn serve as precise templates for the manufacture of custom-made plates to achieve osteosynthesis. No postoperative screw loosening, plate failure or metacarpal fractures occurred, which probably reflects the adequacy of the biomechanics of this custom-made construct and its locking-plate technology. Although the custom-made plate was very effective in the present application, the higher cost of custom-made implants may preclude their use in some cases.

Acknowledgegments

The authors would like to acknowledge Ing. Piero Costa for his technical assistance and Dr Giuliano Pedrani for his assistance in the postoperative management.

Conflicts of interest

Massimo Petazzoni is a partner of and a consultant for the company Traumavet, which owns patents on, produces, and sells the Fixin system. Tommaso Nicetto is also a consultant for Traumavet.
References


Recently it was revealed that the surgical responsibilities for the carried out procedures were not described in sufficient detail within the manuscript. The authors for this paper would like to clarify this matter: Within the manuscript it is described that one surgeon carried out the cementless total hip replacement (THR) and the other surgeon the cemented THR. All these dogs had to be excluded from the final gait analysis study (4 dogs). From that point on, it was decided to continue the study with one surgeon carrying out the cemented and the other one the cementless THRs. The authors apologize for this oversight.