Biomechanical comparison of a novel castless arthrodesis plate with T-plate and cross pin techniques for canine partial carpal arthrodesis

N. J. Burton¹; A. W. Miles²; P. Pollintine²
¹Langford Veterinary Services, University of Bristol, Langford House, Langford, Bristol, U.K.; ²Centre for Orthopaedic Biomechanics, Faculty of Engineering, University of Bath, Bath, U.K.

Keywords
Partial carpal arthrodesis, canine, castless plate

Summary
Objectives: To describe a novel canine castless partial carpal arthrodesis plate (par-CA) and its ex vivo biomechanical comparison with T-plate and cross pinning techniques for canine partial carpal arthrodesis.

Methods: The three implant systems were applied to three cohorts of six forelimbs from Greyhounds euthanatized for reasons unrelated to the study. Intercarpal and carpo-metacarpal palmar fibrocartilage and ligaments were sectioned. Potentiometers were applied between the radial carpal and third metacarpal bones to measure micromotion, and limbs were loaded at 30% of body-weight at 1 Hertz for 10,000 cycles on a servo-hydraulic universal testing machine. Following assessment of micromotion, limbs were loaded to failure at 20 mm/s and ultimate strength, ultimate displacement, and stiffness were measured.

Results: The T-plate (p < 0.01) and par-CA (p < 0.01) had reduced micromotion relative to the cross pin constructs but there was no significant difference between the control, T-plate and par-CA constructs. There was no significant difference in ultimate strength between constructs. Ultimate displacement was reduced in the plated constructs. Stiffness did not differ between constructs.

Clinical significance: The novel par-CA construct was biomechanically similar to the T-plate and both were superior to cross pins in resisting micromotion. There was no difference in load at failure between constructs. The par-CA plate permits radial and ulnar carpal bone compression, a more distal location of the plate to limit impingement, and placement of screws in two metacarpal bones; features which may offer clinical benefits over T-plate fixation.

Introduction
Compromise to the canine carpal palmar fibrocartilage and ligaments most commonly occurs due to traumatic hyperextension injury that is often sustained from a jump or fall (1, 2). An inherited degeneration has also been reported in breeds such as the Shetland Sheep Dog and Border Collie (3). Carpal hyperextension injuries may affect the antebrachiocarpal, middle carpal, or carpometacarpal joints either in isolation or concurrently, with concurrent middle carpal and carpometacarpal injury being most common (4, 5).

Techniques described for management of carpal hyperextension injuries in which the antebrachiocarpal joint is spared include immobilisation in a flexion cast, partial carpal arthrodesis via intramedullary pinning, a dorsally applied T-plate, dorsal twin plating, cross pinning, and pancarpal arthrodesis (2, 4-10). Partial carpal arthrodesis carries the biomechanical advantage over pancarpal arthrodesis of maintained antebrachiocarpal motion during gait with typically 76 degrees or approximately 50% of carpal flexion being maintained postoperatively (6, 11). Management of hyperextension injuries by coaptation cannot be advocated as early reports suggest that this predictably results in unsatisfactory clinical results with persistence of hyperextension, as do attempts at primary ligament repair or augmentation techniques utilising wire or autogenous fascia (4, 5, 12-14).

Widely variable results have been reported clinically for dogs undergoing par-
tial carpal arthrodesis with between 50% to 100% success rates described (8, 10). Some reports describe inferior limb function following partial carpal arthrodesis when compared to the clinical results that can be achieved with pancarpal arthrodesis (10). However, such claims have recently been refuted in a study employing objective gait analysis (11). Poor clinical results with partial carpal arthrodesis have been attributed to multiple factors including poor case selection, the development of antebrachiocarpal osteoarthritis as well as implant loosening, migration, or breakage (6, 8, 10).

An important factor that may influence the success of surgery is the arthrodesis technique employed. Compression and immediate rigid internal fixation are prerequisites for successful arthrodesis (15). Partial carpal arthrodesis techniques that do not strictly adhere to these principles such as cross and intramedullary pinning may predispose to delayed or incomplete fusion of carpal bones. Similarly, those that do not rigidly immobilise both the ulnar and radial carpal bones such as dorsal T-plating or intramedullary pinning could predispose to antebrachiocarpal joint incongruity, production of aberrant callus, and the development of osteoarthritis. In addition, external coaptation has been recommended following arthrodesis for between four and six weeks postoperatively to avoid implant failure (15). Unfortunately, a need for prolonged coaptation is frequently associated with significant postoperative complications compromising short- and long-term limb function (7, 9, 16-18). To the authors’ knowledge, no implant has been shown to reliably result in effective partial carpal arthrodesis without the need for external coaptation.

To date, there are currently no biomechanical studies evaluating the effectiveness of different canine partial carpal arthrodesis techniques. Similarly, there is no implant system for partial carpal arthrodesis permitting rigid internal fixation and compression of the proximal row of carpal bones, intercarpal and carpometacarpal joints fulfilling the criteria to promote expedient arthrodesis. The aims of this study were to present a novel castless canine partial carpal arthrodesis plate (par-CA) and to perform an ex vivo biomechanical comparison of this plate with previously described T-plate and cross pin arthrodesis techniques.

Materials and methods

Implant considerations

The par-CA implant was developed based on perceived clinical and surgical shortcomings of available implant systems for partial carpal arthrodesis. The prototypes were manufactured from 316LVM stainless steel (Figure 1). The proximal aspect of the plate was bevelled by 60 degrees and laterally recessed 20 degrees to avoid impingement on both the cranio-distal aspect and styloid process of the radius respectively during carpal extension. Three holes were incorporated proximally (numbers 1 – 3); a central hole (number 2) accepting a screw in neutral position placed in the radial carpal bone, and oval compression holes (numbers 1 or 3) allowing placement of both a second screw in buttress in the radial carpal bone and a third screw in the ulnar carpal bone placed in compression towards the radial carpal bone. Holes 1 to 3 were angled 60 degrees proximally allowing more distal placement of the plate on both the radial and ulnar carpal bones to avoid impingement of the plate by the radius during extension of the antebrachiocarpal joint. A single 0.9 mm hole per-
forating the plate immediately below the central round hole allowed a small Kirschner wire or hypodermic needle to be placed through the plate into the space immediately distal to the radial carpal bone to define the optimum proximo-distal position of the plate and maintain alignment of the plate during screw placement. The distal component of the plate incorporated design features of a previously described castless plate for pancarpal arthrodesis: there were six progressively divergent 2.7 mm screw holes engaging metacarpal bones three and four, a keel on the underside of the plate increasing dorsal metacarpal contact with the implant, and two further 0.9 mm alignment holes facilitating axial alignment of the distal end of the plate (19). The plate was similarly tapered distally reducing any stress riser at this site. The distal component of the plate was designed to span approximately 60% of the length of metacarpal III and IV in accordance with previously published guidelines for carpal arthrodesis (20).

Cadaveric limb preparation and surgical technique

Eleven pairs of Greyhound forelimbs were obtained from dogs euthanatized for reasons unrelated to the study. Individual dogs were weighed and then the forelimbs disarticulated at the elbow joint, wrapped in saline soaked gauze swabs, individually bagged, archived, and stored at -20°C. Limbs were allowed to thaw for 12 hours prior to implant placement and biomechanical testing.

Limbs were divided into four groups; control (4 limbs), cross pins (6 limbs), T-plate (6 limbs), and par-CA (6 limbs). For the control limbs no implants were placed. For the cross pin limbs, two 1.6 mm diameter cross pins were applied to the carpus in accordance with a previously published partial carpal arthrodesis surgical technique (6). For the T-plate limbs, a seven-hole 2.7 mm T-plate was applied to the dorsal aspect of the radial carpal and third metacarpal (MC III) bones in accordance with a previously described technique, the plate length being chosen to span at least 60% of the MC III length (9). For the par-CA limbs, the prototype plate was applied in accordance with the published user guide for this plate. Following placement of all three implant constructs, a palmar approach was made to the middle carpal and carpometacarpal joints and the palmar carpal fibrocartilage and palmar ligament support sectioned at these levels (21). Care was taken to ensure that the palmar ligament and fibrocartilage support to the antebrachio-carpal joint was not compromised. Palmar ligaments and fibrocartilage were not sectioned in the control group. The palmar process of the radial carpal bone and palmar aspect of MCIII bone were then exposed with a periosteal elevator and two 1.5 mm holes were drilled in these bones. A linear-motion potentiometer was applied to the palmar aspect of the radial carpal bone and MC III with 2.0 cortical screws to measure micromotion between the bones (Figure 2). The soft tissue was then removed from the proximal third of the radius and ulna with a periosteal elevator and the bones transversely osteotomised in the proximal metaphyseal region after which the remaining proximal 6 – 8 cm of the radius and ulna were potted vertically in a bespoke steel square fixture with den-
tal plaster\(^1\). The limb was then loaded using a HC10 servo-hydraulic Universal Testing Machine\(^2\) (Figure 3). The paw was constrained by clamping the phalanges beneath a steel plate to immobilise the digits during carpal loading. Rigid immobilisation of the paw was confirmed once each limb was mounted in the testing machine and loading commenced.

Biomechanical parameters measured were micromotion between carpal and metacarpal bones and ultimate strength, ultimate displacement and stiffness. Micromotion is the recoverable relative movement between the implant and bone associated with the elasticity of the construct and is often used along with migration to quantify the postoperative stability of orthopaedic implants \(^\text{22}\).

**Experiment 1: Assessment of construct micromotion**

A load varying sinusoidally between zero and 30% of individual cadaver total bodyweight was applied at a frequency of 1 Hertz (Hz). Each construct underwent a total of 10,000 cycles to represent a typical frequency of cycles prior to fusion and palmar displacement data were recorded via the potentiometer \(^\text{23}\). Loading at 30% of total bodyweight (approximately 110 N) was chosen to represent load in a standing dog based on previous gait studies identifying 60% of bodyweight to be distributed between the thoracic limbs \(^\text{24}\). The output of the potentiometer was digitised using a 12-bit A/D converter\(^6\), and the resultant data were captured at 20 Hz using HP-VEE software\(^b\). The digitised voltage signal was calibrated against known displacements made using a bench micrometre. Linear regression of the calibration data showed the digital signal to be very strongly correlated with displacement \(r^2 >0.997\), and that the accuracy of the measurement (by considering the relative root mean square error) to be 2.1%. The reproducibility error of the measurement was 3.2%. Data were imported into a spreadsheet programme\(^i\) and the micromotion value for each construct, defined by the displacement amplitude (µm), was calculated at the 2000\(^b\) loading cycle for each construct (Figure 4).

**Experiment 2: Assessment of construct ultimate strength, ultimate displacement and stiffness**

Subsequent to collection of micromotion data, limbs were loaded at a rate of 20 millimetres per second until mechanical failure was deemed to occur when the compressive force reached a peak value, and subsequently began to decrease. The ultimate strength was defined as the maximum force each construct could withstand before failure was recorded in kilonewtons (kN), and ultimate displacement was defined as the displacement (mm) attained when the force reached this maximum value. Stiffness, defined as the gradient of the linear region of the force-deformation graph during the loading phase, was recorded in kN/mm for each construct.

Each construct limb was radiographed and dissected if necessary to determine the mode of structural failure of each construct.

**Statistical analysis**

Analysis was performed using statistical software\(^j\). For each construct (control group, cross pins, T-plate and par-CA) data were assessed for normality using the Kol-

---

\(^{1}\) Dartec-Zwick-Roell LTD, Leominster, Herefordshire, UK

\(^{2}\) 12-bit A/D Converter, DT2821: Data Translation, Inc. Morbboro, MA, USA

\(^{b}\) HP-VEE v5.01 software: Agilent Technologies UK Ltd, Edinburgh, Scotland

\(^{i}\) Excel 2007: Microsoft, Redmond, WA, USA

\(^{j}\) GraphPad InStat, Version 3.06 for Windows 95: GraphPad Software, San Diego, CA, USA
mogetorov-Smirnov test and subsequently either a parametric analysis of variants (ANOVA) with Tukey post hoc test, or a Kruskal-Wallis (nonparametric ANOVA) with Dunn post hoc test were performed. The ANOVA assessed for a significant difference (defined as $p < 0.05$ for all statistical comparisons) between each cohort for the parameter defined (i.e. micromotion, load to failure, ultimate displacement and stiffness) with post hoc tests performed when significance was achieved. In the case of normally distributed data, 95% confidence intervals (CI), standard deviations (SD), and means were defined. For data that were not normally distributed, 95% frequency intervals (FI) and medians were defined.

Results

Experiment 1: Assessment of construct micromotion

Data obtained from all four groups (control, cross pin, T-plate, and par-CA) were normally distributed. The mean micromotion for each of the four groups was as follows: the mean for the control limbs was 120.63 µm (CI: 90.35 to 150.9; SD ± 19.02), cross pins mean was 266.93 µm (CI: 132.59 to 401.27; SD ± 127.99), T-plate mean was 84.95 µm (CI: 8.85 to 161.06; SD ± 72.51), and the par-CA plate mean was 78.07 µm (CI: 31.34 to 124.79; SD ± 44.52). The ANOVA revealed a significant difference in micromotion between the cross pins and T-plate (p < 0.01), and the cross pins and par-CA plates (p < 0.01). There was no significant difference between the control and cross pins, control and T-plate, control and par-CA plate, and the T-plate and par-CA plate constructs.

Experiment 2: Assessment of construct ultimate strength, ultimate displacement and stiffness

Data obtained for the ultimate strength for all four groups (control, cross pin, T-plate, and par-CA) were normally distributed. The mean ultimate strength for each of the four groups was as follows: control limbs was 0.047 kN/mm (FI: 0.012 to 0.054), cross pins was 0.079 kN/mm (FI: 0.025 to 0.262), T-plate was 0.124 kN/mm (FI: 0.062 to 0.428), and the par-CA was 0.122 kN/mm (FI: 0.053 to 0.259) (Figure 7). The ANOVA did not reveal a significant difference between groups.

Mode of failure of each construct was determined by orthogonal radiographs and dissection of each limb following testing. All limbs failed by rupture of the palmar antebraehiociarpal fibrocartilage. In the cross pin group, there was no evidence of implant migration or fracture. One of the T-plate constructs developed a fracture of the MC III distal to the plate, and in another the radial carpal bone screw had loosened (Figure 8). Fracture or implant loosening did not occur in any of the par-CA constructs.

Figure 6

Graph showing mean load–displacement data for control, cross pins, T-plate, and partial carpal arthrodesis plate (par-CA) constructs. The curves illustrate the plastic deformation of each construct (see text for details).

Figure 7

Bar graph showing the median stiffness for the control, cross pins, T-plate, and partial carpal arthrodesis plate (par-CA) constructs. Error bars denote frequency intervals. Differences between groups are not significant.
Discussion

The results of this study demonstrate that the par-CA and T-plate constructs were biomechanically similar and appear superior to cross pinning in reducing intercarpal and carpometacarpal micromotion. Whilst there was no difference in ultimate strength or stiffness tests between the constructs, dorsal plating allows compression of the intercarpal and carpometacarpal joints, which is not achievable with cross pinning. A degree of axial micromotion has been shown to be advantageous in the promotion of pancarpal arthrodesis employing circular skeletal fixation (25-27). However, in a case series of 21 carpi undergoing partial carpal arthrodesis with cross pins, while all carpi ultimately achieved arthrodesis, 22% had incomplete intercarpal fusion, 30% had implant migration postoperatively, and nine percent suffered progressive carpal collapse revealing significant morbidity with this technique (6). Failure of arthrodesis or implant migration are complications that have not been reported with any frequency in cases arthrodesed with either dynamic compression plates or T-plate fixation (9, 10). However, shortcomings of dorsal plating techniques include impingement of the plate on the radius, an inability to provide radio-ulnar carpal bone compression, and the recommendation to employ coaptation for six weeks postoperatively (9, 10). The par-CA is designed to allow radio-ulnar carpal bone compression facilitating primary bone healing and more distal attachment than either a dynamic compression plate or T-plating to abolish radial impingement during carpal extension. The plate has been designed such that the limb may not require coaptation postoperatively. Such a design is advantageous due to morbidities of up to 35% having been reported with coaptation following partial carpal arthrodesis surgery (6). Clinical evaluation of the par-CA is required to fully evaluate the efficacy of these design objectives. It is arguable that partial carpal arthrodesis via palmar plating may be biomechanically superior to dorsal plating as implants span the tension side of the carpus, as well as avoiding plate impingement in carpal extension. Palmar plating for pancarpal arthrodesis has been described in a small case series (28). However, this surgical approach is technically challenging and plate impingement on the radius in carpal flexion may be a concern. In a similar respect to dogs, plating is commonly employed in partial wrist fusion in humans. Hyperextension injuries in humans occur most commonly due to a fall of the patient on to an outstretched hand, with the most common injury being scapholunate ligament injury (29). Partial wrist arthrodesis is also commonly employed for the alleviation of pain attributable to osteoarthritis (30). Dorsal plating techniques such as the use of the Spider plate\(^k\) appear to offer superior results in selected cases of wrist arthrodesis when compared to arthroscopic Kirschner wire or cannulated screwing, or open approach stapling and intramedullary pin techniques (30, 31). It is interesting to note that as part of the surgical technique for dorsal plating in humans, the plate is recessed in a channel within the bone to negate the risk of impingement of the implants on bone when the wrist is extended (30). Dorsal recession of a cortical bone graft or plate in pancarpal arthrodesis in the dog has been described, however such a technique has yet to be adopted for partial carpal arthrodesis (32).

There are limitations to this \textit{ex vivo} study. Firstly, our \textit{ex vivo} limbs did not accurately mimic the movement of the thoracic limb as would be observed clinically. We elected to immobilise the digits of the foot during limb testing to stop the manus from slipping while the limb was loaded, thus movement of the distal limb bore no resemblance to the angular excursion of the foot that would occur clinically, and thus the moments generated by the distal limb during stance. Secondly, we elected to test each construct with the limb in a standing position and with standing bodyweight applied in pure axial compression. Forces applied to the carpus and implants in the walking and running dog would be greater than those at rest but the precise forces acting through a partial fused carpal joint as a function of different activity levels are currently ill-defined. Thirdly, although it was not the purpose of this study to analyse the plastic deformation of the constructs, it is clear from Figure 6 that plastic deformation did occur in some (but not all) specimens. This is evident from the decrease in the gradient of the load-displacement curve in some specimens. Any plastic deformation resulting from partial pull out of the screws that hold the plate in place could lead to excessive motion and instability of the construct, and which could loosen further during cyclic loading leading ultimately to failure.

In summary, the par-CA plate and T-plate constructs were similar and superior to cross pinning in resisting micromotion. There was no difference in ultimate strength or stiffness between constructs. Ultimate displacement of the plate specimens was significantly less than the control and cross pin specimens. The par-CA plate is designed to allow radio-ulnar carpal bone compression and more distal plate application than with T-plate fixation. These features, combined with a design which may negate the need for postoperative coaptation may reduce morbidity previously associated with canine partial carpal arthrodesis. Clinical trials of the par-CA implant are required to evaluate its clinical efficacy.

\textsuperscript{k} Spider Limited Wrist Arthrodesis System: Kinetikos Medical, San Diego, CA, USA.
Acknowledgements

The authors would like to thank Orthomed (UK) for the manufacture and donation of the prototype plates and screws used in the study.

Conflict of interest

The castless canine partial carpal arthrodesis plate (par-CA) which was used in this study was designed by the author (NJB) in conjunction with Orthomed (UK), which owns the design and commercial sale of the castless partial arthrodesis plate system.

References