Ground reaction force profiles after partial and pancarpal arthrodesis in dogs

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Keywords
Ground reaction forces, kinetic gait analysis, partial carpal arthrodesis, pancarpal arthrodesis, hyperextension trauma

Summary

Objectives: To evaluate and compare long-term functional outcome after partial carpal arthrodesis and pancarpal arthrodesis in dogs using kinetic gait analysis.

Methods: Fourteen dogs with 19 partial carpal or pancarpal arthrodeses were retrospectively examined and underwent force-plate gait analysis. Mean times since surgery were 29.4 and 24.4 months for pancarpal and partial carpal arthrodesis respectively. Vertical and braking-propulsive ground reaction force profiles were compared between treatment groups, and to those of normal dogs (control group) using Kruskal-Wallis one-way analysis of variance.

Results: With the exception of time to vertical peak that occurred earlier in dogs with pancarpal than in dogs with partial carpal arthrodesis (p < 0.01), there was no difference between the two treatment groups. Several parameters differed significantly between operated and healthy dogs (p < 0.01): vertical impulses were significantly lower in both treatment groups, braking forces and impulses were also reduced after both techniques. Propulsive forces and impulses were only reduced in dogs with pancarpal arthrodesis. When comparing gait parameters of sound limbs of unilateral operated dogs to those of control dogs, braking forces and impulses (p < 0.01; p < 0.05) were significantly higher in the sound legs of unilateral operated dogs.

Clinical Significance: Long-term outcome after partial carpal and pancarpal arthrodesis is good and comparable to each other. Propulsive action may be altered more in dogs with pancarpal arthrodesis.

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Introduction

Injuries of the carpal joints such as hyperextension injuries, shearing injuries, luxations with multiple ligament damage, and comminuted fractures are common, and frequently lead to irreparable joint damage. Most authors report the carpo-metacarpal joint to be the most affected, representing up to 51% of the cases, whereas others have found the antebrachiocarpal joint or the middle carpal joint to be injured most often (1–5, 7). Partial carpal and pancarpal arthrodesis have been used as successful salvage techniques for these cases.

With pancarpal arthrodesis (PCA), all three carpal joints are fused and the carpus is rendered completely immobilised. Pancarpal arthrodesis is indicated when injury or disease has destroyed the entire carpal or the antebrachiocarpal joint only. Pancarpal arthrodesis can be performed using dorsal plating, medial plating, palmar plating or external skeletal fixation (3, 6–9). If only the middle or carpometacarpal joint row is destroyed, a partial carpal arthrodesis (PAR) can be performed fusing only these articulations, thus preserving motion of the antebrachiocarpal joint. Previously described surgical techniques for PAR include an intramedullary pinning technique, application of a dorsal dynamic compression plate or T-plate, and dorsal twin plating (4, 10–13).

Pancarpal arthrodesis has been the most widely advocated technique for treatment of carpal injuries, regardless of the joint level involved (1, 2, 4, 14). It was feared that PAR could cause abnormal stresses on the antebrachiocarpal joint or on the palmar ligament support (1, 2). Overload and painful dysfunction of the distal joint row is also the main reason why selected fusion of the radiocarpal joint is avoided (3). Additionally, injury to more than one of the main carpal joint rows can be present. This can be difficult to assess on preoperative stress radiographs and may be overlooked. Concurrent injuries to the antebrachiocarpal joint could result in unsatisfactory limb function and osteoarthritis of the antebrachiocarpal articulation (4).

The main reason to prefer PAR for injuries of the middle carpal and carpometacarpal joints is to preserve mobility of the antebrachiocarpal articulation (10–13).

Outcome after PAR and PCA has been evaluated based on postsurgical compli-
restricted carpal motion has been described to modify angular excursions of other joints, but a potential effect of absent or impaired carpal excursions on ground reaction force (GRF) parameters has not yet been described (16).

The purpose of this study was to objectively evaluate long-term functional outcome after PAR and PCA in dogs using kinetic gait analysis, and to compare the vertical and braking/propulsive parameters between dogs that had undergone PAR or PCA, and normal dogs. The influence of extension and flexion (in dogs with PAR) angles of the operated carpal joints on ground reaction force parameters was also investigated.

Table 1 Means and ranges of age, weight, follow-up, extension and flexion angles.

<table>
<thead>
<tr>
<th></th>
<th>Pancarpal arthrodesis (n = 10)</th>
<th>Partial carpal arthrodesis (n = 9)</th>
<th>Control group (n = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>Mean (range)</td>
<td>Mean (range)</td>
<td>Mean (range)</td>
</tr>
<tr>
<td></td>
<td>7.8 (4 - 13)</td>
<td>7.0 (3 - 12)</td>
<td>5 (2 - 13)</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>28.4 (17.4 - 34.5)</td>
<td>27.5 (20.3 - 32.4)</td>
<td>25.6 (20 - 34.7)</td>
</tr>
<tr>
<td>Follow-up (months)</td>
<td>29.4 (14 - 38)</td>
<td>24.4 (10 - 65)</td>
<td>NA</td>
</tr>
<tr>
<td>Extension angle (°)</td>
<td>13.3 (10 - 16)</td>
<td>19.8 (12 - 26)</td>
<td>NA</td>
</tr>
<tr>
<td>Flexion angle (°)</td>
<td>NA</td>
<td>76 (45 - 90)</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA = not applicable

Materials and methods

Dogs

Medical records of dogs that had undergone PAR or PCA between 2001 to 2007 were retrospectively collected in three different clinics. Inclusion criteria were a body weight of at least 15 kg to allow for force-plate gait analysis, and a follow-up period of at least 10 months. The owners of the dogs were contacted and were asked to bring their dogs for clinical and radiological examination as well as for gait analysis. Exclusion criteria were a history of medical or surgical treatment for orthopaedic problems other than PAR or PCA. Dogs of owners that were willing to participate in the study had to have a normal general physical, orthopaedic and neurological examination prior to inclusion in the study.

Because we included patients with bilateral surgeries, inter-dog comparison of force-plate data was not possible; therefore data of a control group of dogs was obtained. The control group consisted of healthy dogs based on orthopaedic and neurological examination. The control dogs belonged to friends or staff, or were organised through breeding clubs. Body weight of the control group was matched to the treatment group.

Clinical evaluations

Body weight, age, type of surgical technique performed, and follow-up time were noted. The amount of extension of both carpal joints was measured by use of a goniometer while the dogs were fully weight-bearing on the affected limb, and was recorded in degrees exceeding 180°. The maximal carpal flexion angle was measured in patients with PAR, and was recorded in degrees lower than 180°. Mediolateral and dorsopalmar radiographs were taken of both carpal joints and the paws in the non-sedated dogs. Radiographs were evaluated for signs of implant loosening, and degenerative joint disease in the dogs with PAR.

Table 2 Radiographical findings at follow-up.

<table>
<thead>
<tr>
<th></th>
<th>Pancarpal arthrodesis (n = 10)</th>
<th>Partial carpal arthrodesis (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degenerative joint disease: Antebrachiocarpal joint</td>
<td>NA</td>
<td>8</td>
</tr>
<tr>
<td>Accessory carpal bone displacement</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Antebrachiocarpal joint: fusion complete</td>
<td>7</td>
<td>NA</td>
</tr>
<tr>
<td>Antebrachiocarpal joint: fusion incomplete</td>
<td>3</td>
<td>NA</td>
</tr>
<tr>
<td>Degenerative joint disease: Metacarpophalangeal joints and phalangeal joints</td>
<td>Absent</td>
<td>Absent</td>
</tr>
</tbody>
</table>

NA = not applicable

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and degenerative joint disease of the metacarpophalangeal and phalangeal joints in both treatment groups.

**Force-plate gait analysis**

Kinetic gait analysis was performed using a force plate\(^b\) embedded in an 8.0 m runway, and a specialised computer program\(^c\). The dogs were allowed to explore the environment before the measurements were started. The patients were led across the force plate by their owners, who had been instructed on how to lead their dogs before starting the measurements. At least six valid trials per limb were recorded at trotting velocity. A valid trial had to have a distinct footstep of one forelimb, followed by a distinct step of the ipsilateral hindlimb. Dog and handler velocity had to be 2.0 m/s (±0.15), and acceleration and deceleration variability had to be smaller than ±0.3 m/s\(^2\).

The following measurements were taken and processed for statistical analysis: total stance time (ST; ms), peak vertical forces (PVF; %BW), vertical impulses (VI; %BW-s), time to vertical peak (TVP; % stance time), peak braking forces (PBF; %BW), braking impulses (BI; %BW-s), time to braking peak (TBP; % stance time), propulsive peak forces (PPF; %BW), propulsive impulses (PI; %BW-s), and time to propulsive peak (TPP; % stance time).

**Statistical analysis**

Data were analysed by use of statistical software program\(^d\). Data from left and right forelimbs of each control dog were averaged prior to analysis. Means of the valid trials were compared between dogs with PAR, dogs with PCA, and normal dogs (control group) using Kruskal-Wallis one-way analysis of variance. Bonferroni-Dunn adjustment was used to evaluate the differences between the three groups. Relationships of carpal extension and flexion angles of dogs with PCA and PAR respectively, and GRF was investigated by means of Pearson’s correlation test. In order to evaluate for potential load redistribution, we also analysed the relationship of gait parameters between the sound limbs of unilaterally operated dogs (PAR and PCA) with those of the control group using the unpaired Student’s t-Test. Data are reported as means ± one standard deviation (SD). Statistical significance was set at p < 0.05.

**Results**

**Dogs**

Medical records of 17 dogs with PAR, and 33 dogs with PCA, and one dog with both procedures, each of which matched the inclusion criteria were identified. Out of these 51 patients, 14 participated in the study. From the remaining, 12 were lost to follow-up, six had died in the meantime, and one had concomitant orthopaedic problems anamnestically. Fifteen owners declined participation because they lived too far away, their dog had other health problems, or because they had no time. Owners of three dogs, one with PAR and two with PCA, did not participate because they were not satisfied with the outcome of the surgery.

Seven dogs with nine PAR were examined. In four patients, surgery had been performed unilaterally, in two bilaterally, and one patient had a PCA on the left as well as a PAR on the right forelimb. The PCA group consisted of seven dogs with 10 arthrodeses. Surgery was performed unilaterally in five patients and bilaterally in two. All but one owner of a dog with a PCA were satisfied with the procedure. Clinical, radiographical, and surgical information of the operated dogs are summarised in Table 3.

The control group consisted of 22 dogs that did not have any clinical evidence of orthopaedic disease. There were no significant differences between the treatment and control groups for body weight.

**Force-plate gait analysis**

The mean ± SD of the force-plate data of the affected limbs of dogs with PAR, PCA, and of the dogs in the control group are depicted in Table 4. The only parameter that differed significantly between dogs with PAR and PCA was the TVP measurement that occurred significantly later in dogs with PAR.

Several parameters were significantly lower in both treatment groups compared to the control group (Table 4; Fig. 1). No significant difference was found for PVF between dogs with PAR or PCA, and the dogs of the control group. There were not any differences between ST and TVP between the operated dogs and the control

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\(^{a}\) OR6–7: Advanced Medical Technologies Inc., Watertown, MA, USA

\(^{b}\) Acquire 7.3: Sharon software, MA, USA

\(^{c}\) GraphPad Prism, version 4.0: GraphPad Software, San Diego, CA, USA

\(^{d}\) Hybrid DCP: Jorgensen Laboratories, Loveland, CO, USA

\(^{e}\) Unilock System: Synthes AG, CH

\(^{f}\) Twin dynamic compression plate

**Table 3.** Summary of applied surgical methods.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>PAR (n = 10)</th>
<th>Carpal arthrodesis (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial dynamic compression plate</td>
<td>1</td>
<td>Intramedullary pins 1</td>
</tr>
<tr>
<td>Dorsal dynamic compression plate</td>
<td>9</td>
<td>Twin dynamic compression plate 3</td>
</tr>
<tr>
<td>Combination (pins, IF)</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

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group. Vertical impulses were significantly lower in dogs that were treated with either method compared to the healthy dogs (p < 0.01).

The PBF and BI were significantly higher (less negative) in dogs with both PAR or PCA when compared to the control group (p < 0.05; p < 0.01). The TBP was significantly shorter in PAR when compared to the normal dogs (p < 0.01).

The PPF and PI were significantly lower after PCA as compared to the control group (p < 0.01). There was no any difference in propulsive parameters between dogs with PAR and healthy dogs.

When comparing the gait parameters of the sound limbs of the unilateral operated dogs to those of the control dogs, a significant difference was found for the PBF (p < 0.01) and the BI (p < 0.05). These values were lower (more negative) in the sound legs of the unilateral operated dogs.

No significant difference was found between the ranges of extension or flexion angles and any of the investigated force-plate parameters in both treatment groups.

### Discussion

This study was aimed at evaluating and comparing long-term functional outcome after PAR and PCA in dogs using kinetic gait analysis. Vertical force-plate parameters did not differ between dogs with PAR and PCA, and no large differences were found in braking and propulsive forces and impulses between the treatment groups.

However, propulsive forces and impulses were significantly lower in dogs that had undergone PCA when compared to normal dogs. Dogs with PAR had near-normal propulsive parameters. Extension and flexion angles were not associated with changes in any of the GRF within treatment groups.

Objective evaluation of limb loading using force-plate gait analysis confirmed that satisfactory limb function can be expected in dogs after both PAR and PCA. The lack of significant differences in ST and PVF between dogs with PAR or PCA and normal dogs indicates that both surgeries resulted in a relatively pain-free ability to load the affected limb. On the other hand, the VI were smaller after both surgical techniques compared to normal dogs, indicating that some degree of alteration of vertical limb loading occurred. The impulse is the area under the force curve, or the average force times the ST, respectively. As both PVF and ST time did not significantly differ between groups, one would expect no difference in the VI either. However, although not reaching significance the mean stance times and PVF were smaller than those of the normal dogs in both treatment groups. The lack of significant differences in stance times could be a type II error due to insufficient case numbers. Both treatment groups had a tendency for the VTP to occur earlier during the stance phase, indicating that the limbs were starting to unload earlier during the stance phase. Significant difference to the control group was not reached, but dogs with PCA had a significantly shorter VTP compared to patients with PAR.

Both the PBF and BI were significantly lower in patients of both treatment groups compared to normal dogs. Because braking forces are higher than propulsive forces in the thoracic limbs, it is possible that minor changes in gait do mainly affect braking forces. The TBP were also shorter in dogs of both treatment groups compared to the control dogs, although this was only significant for patients with PAR. This is likely to be related to the lower BI, and reflects a lower braking ability of the affected limbs. Interestingly, the PBF and the BI were found to be higher in the contralateral sound limb in unilaterally affected dogs when compared to the control dogs.

### Table 4

<table>
<thead>
<tr>
<th>Gait parameters</th>
<th>Pancarpal arthrodesis (n = 10)</th>
<th>Partial carpal arthrodesis (n = 9)</th>
<th>Control group (n = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical force</strong></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Peak (% body weight)</td>
<td>115.50 ± 8.64</td>
<td>114.20 ± 16.34</td>
<td>117.20 ± 6.79</td>
</tr>
<tr>
<td>Impulse (% body weight seconds)</td>
<td>14.62 ± 1.46</td>
<td>14.79 ± 1.03</td>
<td>16.90 ± 1.39</td>
</tr>
<tr>
<td>Time to peak (%)</td>
<td>42.84 ± 2.59</td>
<td>46.48 ± 1.27</td>
<td>47.15 ± 6.43</td>
</tr>
<tr>
<td>Stance time (milliseconds)</td>
<td>248.10 ± 23.23</td>
<td>252.60 ± 10.33</td>
<td>266.80 ± 21.22</td>
</tr>
<tr>
<td><strong>Braking force</strong></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Peak (% body weight)</td>
<td>-13.45 ± 2.64</td>
<td>-12.73 ± 2.19</td>
<td>-15.66 ± 1.44</td>
</tr>
<tr>
<td>Impulse (% body weight seconds)</td>
<td>-1.06 ± 0.28</td>
<td>-0.97 ± 0.27</td>
<td>-1.37 ± 0.19</td>
</tr>
<tr>
<td>Time to peak (%)</td>
<td>23.76 ± 8.76</td>
<td>24.3 ± 4.73</td>
<td>29.23 ± 4.04</td>
</tr>
<tr>
<td><strong>Propulsive force</strong></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Peak (% body weight)</td>
<td>4.51 ± 1.38</td>
<td>5.99 ± 1.46</td>
<td>7.35 ± 1.71</td>
</tr>
<tr>
<td>Impulse (% body weight seconds)</td>
<td>0.25 ± 0.13</td>
<td>0.39 ± 0.12</td>
<td>0.52 ± 0.18</td>
</tr>
<tr>
<td>Time to peak (%)</td>
<td>70.73 ± 3.73</td>
<td>69.44 ± 5.22</td>
<td>75.22 ± 9.54</td>
</tr>
</tbody>
</table>

Key: ¶ value significantly different between limbs with partial carpal and pancarpal arthrodesis, # value significantly different between limbs with partial carpal arthrodesis and normal dogs, ß value significantly different between limbs with pancarpal arthrodesis and normal dogs. %: percent of total stance time.
therefore seems that there is a redistribution of braking action to the healthy limb in unilaterally affected dogs.

The propulsive forces and impulses did not differ between dogs with PAR and normal dogs, whereas dogs with PCA had significantly lower PPF and PI than normal dogs. It was shown in a recent publication that a positive work of the flexor muscles of the carpal joint persists throughout the stance phase, which is likely to produce a propulsive effect (18). The inability to flex the carpus after PCA may prohibit the propulsive action of the flexor muscles, and as such, reduce the propulsive forces. A correlation of maximum flexion angles in dogs with PAR with GRF parameters could not be demonstrated in this study.

Functional alterations of one joint are likely to induce multiple adaptive mechanisms in terms of angular excursions and power distributions at other levels of the limb. A previous study used kinematic gait analysis to describe the effects of artificially decreased range of motion in the carpal joint persistent throughout the stance phase, which is likely to produce a propulsive effect (18). The inability to flex the carpus after PCA may prohibit the propulsive action of the flexor muscles, and as such, reduce the propulsive forces. A correlation of maximum flexion angles in dogs with PAR with GRF parameters could not be demonstrated in this study.

Dogs with PCA tended to have a steeper standing angle (mean: 13.3°) than dogs with PAR (mean: 19.8°), but the angles were within the described ranges of 10°-40° for healthy dogs (9, 11). Carpal flexion was naturally eliminated in dogs with PCA. The maximal carpal flexion angles in dogs with PAR ranged from 45° to 90° (mean 76°). This is only approximately half of the normal maximal range of motion in flexion, which has been described to be around 150° (11, 15, 17). This is consistent with other reports describing markedly reduced maximal carpal flexion angles between 40 and 70° (11, 13). The reduced flexion is partially due to loss of motion of the middle carpal and carpometacarpal joints, but it is probably also caused by fibrosis of the antebrachiocarpal joint capsule and surrounding soft tissues as a result of iatrogenic injury during surgery or prolonged postoperative immobilisation.

Development of osteoarthritis of the radiocarpal joint is thought to have poten-
tially detrimental effects on limb function. The incidence of antebrachiocarpal osteoarthritis following PCA has previously been described to be as low as 15.5% (11). Degenerative joint changes were found in nearly all patients of this study, as well as in those of another study (13), but were considered minor in the majority of cases. Previous studies have reported normal or near-normal limb function in approximately 70% of patients with PAR, whereas only 50% of patients were considered to have satisfactory limb function in another study (4, 11, 13). The findings of this study supports the contention that good limb function can be achieved with PAR.

The accessory carpal bone was displaced proximally in patients with both PAR and PCA, indicating insufficiency of the distal ligamentous support. Although this has been considered to be an indication to perform PCA, proximal displacement of the accessory carpal bone did not seem to negatively affect outcome in the dogs with PAR within the present study as well as in those of a previous study (10, 11, 19).

This study has several drawbacks, a major one being the limited number of cases. It was surprisingly difficult to recruit owners that were willing to participate in the study. Three owners were discontent with the outcome, thus this should not have caused bias in patient selection. It is possible that some of the force-plate parameters would have reached significance if larger case numbers had been evaluated. The inclusion of dogs with bilateral surgeries is also unfavourable because of potential load redistribution to the hindlimbs. Although by selecting a control group of dogs that was matched for body weight, the results may have been influenced by variations of ground reaction forces between dog groups. The fact that the patients were led across the force plate by their owners may have slightly enhanced variability of the gait parameters. Another disadvantage was the inclusion of dogs in which different techniques had been applied. This was due to the time frame of the study, the different preferences of the surgeons of the involved clinics, and because techniques had changed through time. The type of stabilization used might not be a significant factor for the long-term outcome after PCA, but it may influence results in dogs with PAR.

We conclude that vertical, braking and propulsive gait parameters are similar between dogs that have undergone PAR and PCA, and that both procedures result in good, albeit not completely normal limb function. Vertical impulses and braking parameters were reduced in both treatment groups, indicating a reduced ability for braking action. Propulsive parameters were only reduced in dogs with PCA. We admit that our results could be subject to type II errors due to insufficient case numbers.

References