Outcome of Repair of Distal Radial and Ulnar Fractures in Dogs Weighing 4 kg or Less Using a 1.5-mm Locking Adaption Plate or 2.0-mm Limited Contact Dynamic Compression Plate

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Abstract

Objectives  Retrospective evaluation of repairing distal radial and ulnar fractures in small breed dogs with the Synthes 1.5-mm locking Adaption plate system and compare results in a similar group of patients repaired with the Synthes 2.0-mm limited contact-dynamic compression plate (LCDCP).

Methods  Electronic medical records from one specialty referral centre were reviewed from March 21, 2010, to October 9, 2015, for patients weighing less than or equal to 4 kg that had a distal one-third radial and ulnar fracture repaired with a Synthes 1.5-mm locking adaption plate or Synthes 2.0-mm LCDCP. Further inclusion criteria included application of the plate to the cranial surface of the radius via open reduction and internal fixation.

Results  Six 1.5-mm Adaption plates and 7 2.0-mm LCDCPs were used to repair 13 distal radial and ulnar fractures in 12 dogs. There were three major complications in the 1.5-mm adaption plate group (one plate fracture, one screw pull-out and one fracture through a distal screw hole) and one major complication in the 2.0-mm LCDCP group due to a re-fracture. All patients without a complication had good or excellent functional outcome.

Clinical Significance  The authors recommend that the 1.5-mm Adaption plate be used only when a 2.0-mm LCDCP would not allow for a minimum of two screws in the distal segment and at the discretion of the surgeon.

Introduction

Distal radial and ulnar fractures are common in small breed dogs.1–5 Complications in healing may occur secondary to the decreased vascular density at the distal diaphyseal–metaphyseal junction of the radius in this population in comparison to larger breed dogs.6 Additionally, small breed radii are more likely to sustain distal radial fractures with less relative force. This is believed to be secondary to morphologic differences noted in the radius; the toy breed radius and ulna have a significantly lower relative area moment of inertia than that of larger breed dogs.2 Up to 83% of externally coapted radial and ulnar fractures in these patients may suffer malalignment or non-union, leading to the recommendation for rigid fixation; this has been reported to be successful with external skeletal fixator rigid fixation, minimally invasive plate osteosynthesis and open reduction with internal rigid fixation.1,7 A recent report revealed results in 20 dogs less than 6 kg using a 2.0-mm locking compression plate.
plate for repair of distal radial and ulnar fractures. Currently, there are no reports of using the 1.5-mm locking adaption plate in a clinical series of dogs. The small amount of bone available for screw purchase in small breed dogs can make repair challenging. The availability of a 1.5-mm locking system allows for more screws to be placed per centimetre of bone during repair than with a 2.0-mm plate. The objective of this case series was to report the outcome of distal radial and ulnar fracture repair in dogs weighing 4 kg or less using the 1.5-mm locking Adaption plate system or a 2.0-mm limited contact compression plate. Our hypothesis was that distal radial and ulnar fractures in dogs weighing 4 kg or less using these two methods of fixation would be similar.

Materials and Methods

Inclusion Criteria
The electronic medical records from one specialty referral centre (Animal Specialty Group, Los Angeles, California, United States) were reviewed from March 21, 2010 to October 9, 2015 for patients weighing 4 kg or less with a distal third radial and ulnar fracture repaired with a 1.5-mm locking Adaption plate (DePuy Synthes Vet, West Chester, Pennsylvania, United States) or 2.0-mm limited contactdynamic compression plate (LC-DCP, DePuy Synthes Vet). Further inclusion criteria included application of the plate to the cranial surface of the radius via open reduction and internal fixation. Cases that lacked radiographic follow-up for a minimum of 8 weeks were excluded from the study.

Patient and Fracture Descriptions
Data collected included surgeon together with the breed, sex, date of birth, surgery date, cause of fracture, side affected and limb function postoperatively of the patient. Preoperative, postoperative and follow-up radiographs were evaluated and measured using eFilm imaging software (Merge Healthcare Inc., Chicago, Illinois, United States). Measurements performed included diaphyseal width, epiphyseal width, distal fragment length, distal physis length (if applicable) and total radius length. The distal segment to total radius length ratio was calculated.

Stabilization Method
All procedures were performed by a diplomate of the American College of Veterinary Surgeons (ACVS) or an ACVS resident under immediate supervision of a diplomate. All reductions and stabilizations were performed via an open approach. The following data were collected from the surgical report and postoperative radiographs: implant type (1.5-mm locking Adaption plate or 2-mm LC-DCP), plate length (number of holes) and number of cortical or locking screws in each fragment. The plate chosen for fracture repair was at the discretion of the surgeon in a routine repair of the fracture. The ratio of locking to cortical screws was based on surgeon preference. Postoperative reduction was also evaluated for translational malalignment, determined as a ratio between the maximal displacement and the width of the bone at the level of the fracture site as previously described.

Implants
The locking adaption plate has threaded round holes and can only function as a bridging or neutralization plate, but not as a compression plate (Fig. 1). It can be cut to length, to create plates of up to 12 holes. The adaption plate has 2.07 holes/cm and is 1.0-mm thick and 4.25-mm wide. The 2.0-mm LC-DCP can accept either 1.5- or 2.0-mm cortical screws (DePuy Synthes Vet). They are available in lengths from 4 to 14 holes and have 1.6 holes/cm. The LC-DCP plates are 1.2-mm thick and 5.5-mm wide. The out-of-plane calculated area moment of inertia for the 1.5-mm adaption plate and 2.0-mm LC-DCP are 0.11 and 0.46 mm² through the hole and 0.16 and 0.52 mm² between the holes, respectively (Horan TJ, Principal Engineer, DePuy Synthes Vet, E-Mail message to author, April 11, 2017).

Outcome Evaluation
Follow-up radiographs were evaluated for healing progression. Healing was evaluated retrospectively based on criteria developed by the International Society of Limb Salvage as described previously. The following radiographic scoring defined union as fusion of the fracture line, the presence of bridging callus, or the disappearance of the fracture line as seen on at least one aspect of each radiographic view: 1 = poor union less than 25% (no evidence of callus); 2 = fair union 25 to 50% healing; 3 = good union greater than 50 to 75% healing; and 4 = excellent union greater than 75% healing. These estimations were determined by both a diplomate of ACVS and an ACVS resident.

Any complications recorded in the medical record were noted. Complications were considered minor if they were managed without surgery and major if they required surgery or negatively influenced the expected outcome. The overall
use of the limb was graded as excellent (return to normal function), good (mild intermittent lameness), fair (frequent mild to moderate lameness), or poor (permanent moderate to severe lameness).

**Statistical Evaluation**

A statistical consulting service (Dr. Su Statistics—Statistical consulting [drsus.statistics@gmail.com]) and software package (SAS/STAT 9.4: SAS Institute Inc., Cary, North Carolina, United States) were used to evaluate the data. Frequency tables and descriptive statistics were used to summarize the potential variables of interest. Fisher’s exact tests (for categorical variables) and Wilcoxon rank-sum tests (for continuous variables) were used to determine if there were any significant differences between the groups (1.5-mm Adaption or 2.0-mm LC-DCP) for (1) complication status and (2) the other variables (breed, sex, age, weight, days to surgery, fracture type, distal fracture segment length, radius length, epiphysis width, diaphysis width, locking density, total screws, postoperative reduction and follow-up radiograph scores).

Logistic regression was proposed to investigate if there was any relationship between complication and predictors of interest. As the sample size was small, Firth’s penalized likelihood approach was implemented, and the predictors of interest were considered one at a time. Likelihood ratio tests were used to determine if any predictors were significant, that is, if there was a relationship between the outcome variable (complication) and the predictors. Odds ratio (OR) estimates for the predictors and the corresponding 95% profile likelihood confidence intervals (CI) were computed. Note that if the CI of a predictor did not contain 1, then it implies the effect was significant. A p-value of ≤0.05 was considered significant.

Kappa statistics were proposed to compare inter-observer variability in the postoperative reduction and re-examination scores between the two authors. Possible values of kappa statistics range from −1 to 1, with 1 indicating perfect agreement, 0 indicating completely random agreement and −1 indicating perfect disagreement. Kappa values 0 to 0.20 indicate slight agreement, 0.21 to 0.40 indicate fair agreement, 0.41 to 0.60 indicate moderate agreement, 0.61 to 0.80 indicate substantial agreement and 0.81 to 1 indicate almost perfect agreement.

### Results

**1.5-mm Adaption Plates**

Seven small breed dogs were identified as having been treated with a 1.5-mm locking adaption plate (Table 1, Fig. 2). One patient was excluded due to not having a minimum of 8 weeks’ postoperative radiographic follow-up. Six dogs with a median age of 1.52 years (range: 0.39–12.19 years) weighing 4 kg or less (median 2.54 kg, range: 1.5–3.8 kg) were treated for distal radial and ulnar fractures by two surgeons (AMS, SAB). Breeds included Miniature or Toy poodle (n = 2), Yorkshire terrier (n = 2), Miniature Pinscher (n = 1) and Pomeranian (n = 1). The cause of fracture was reported to be a jump, fall, or drop from a height in five cases and other or unknown in one case. There were two transverse, three short oblique and one short oblique with butterfly fragment fracture configurations.

The median diaphyseal width was 5.5 mm (range: 5–7 mm) and median distal segment length was 12.5 mm (range: 10–19 mm) with a median distal segment-to-total radius length ratio of 19% (range: 15–27%). Two patients were juvenile with open physes. No fracture repairs bridged the open physes in these patients. Removing the length of the open physes from the calculations reduced the effective plating length of the distal segment to a median of 12 mm (range: 8–15 mm). The new median distal segment ratio was 19% (range: 10–25%).

The median length of the plates was five holes (range: 5–7 holes) with a total of two holes in the distal fragment in all cases. Locking screw density was variable and determined by surgeon preference. The median was 100% (range: 0–100%). One author scored three patients as having perfect reduction and three with near-anatomical reduction. The second author scored one patient as having perfect reduction, four with near-anatomical reduction and one with less than 10% from perfect reduction. The median radiographic score averaged between the two observers at the first re-examination was 2 (range: 1–4) and 4 at the second re-examination. It is noted that the one patient with a score of 4 at the first re-examination was 20 months postoperative, as it was never returned for the recommended 4- and 8-week radiographs.

Five of six patients had a splint placed postoperatively for a range of 3 to 4 weeks. No complication was noted in the one patient without a bandage. Median follow-up, including

### Table 1

**Summary of variables between the two treatment groups**

<table>
<thead>
<tr>
<th></th>
<th>Age (y)</th>
<th>Weight (kg)</th>
<th>Distal segment length (mm)</th>
<th>Radius length (mm)</th>
<th>Distal segment ratio</th>
<th>Distal phys length (mm)</th>
<th>Adjusted distal segment length (mm)</th>
<th>Adjusted distal segment ratio</th>
<th>Epiphysis width (mm)</th>
<th>Diaphysis width (mm)</th>
<th>Distal screw nr.</th>
<th>No. of major complications</th>
</tr>
</thead>
</table>
| **1.5-mm adaption**
  nr. = 6 | 1.52 (0.39–12.19) | 2.54 (1.5–3.8) | 12.5 (10–19) | 70 (48–80) | 19% (15–27) | 4.5 (4–5) | 12 (8–15) | 19% (10–25) | 11.5 (10–13) | 5.5 (5–7) | 2 (0) | 3 |
| **2.0-mm LC-DCP**
  nr. = 7 | 1.43 (0.76–2.11) | 2.46 (2.36–4.0) | 19 (15–25) | 81 (57–112) | 24% (13–30) | 4 (0) | 17 (15–25) | 21% (13–30) | 11 (11–16) | 6 (5–7) | 2 (1) | 1 |

Abbreviation: nr., number.

Notes: All values given are median (range).
phone conversations, was 5.85 months (range: 3.91–49.94 months).

There were three major complications (Table 2) in fractures repaired with the 1.5-mm Adaption plate. One patient (Case 1, 1 year old) developed ulnar resorption and failure of fixation via plate breakage 3 months postoperatively. The fracture was revised with a new cranial plate and additional medial plate. The radial fracture was healed after 2 months without resolution of the ulnar resorption (Fig. 3). The patient was noted to have a mild lameness at last re-examination. A second patient (Case 2, 12.2 years old) with all cortical screws in an Adaption plate suffered screw pull-out and fixation failure 1 month postoperatively (Fig. 4). The external fixator was removed 3 months later. While the patient failed to be presented for any further follow-ups, a later unrelated emergency visit to the hospital had no mention of a lameness. A third patient (Case 3, 3 months old) suffered a fracture through a distal screw hole 7.5 months postoperatively (Fig. 5). The patient was managed with external coaptation. Phone interview with the owner revealed that the patient had made full recovery and had normal function. The remaining three patients have radiographic evidence of full healing and physical examination findings of excellent outcome.

### 2.0-mm Limited Contact Compression Plate
Eleven small breed dogs were identified as having been treated with a 2.0-mm LC-DCP (Fig. 6). Five patients were excluded due to not having a minimum of 8-week postoperative radiographic follow-up. Six small breed dogs with a median age of 1.43 years (range: 0.76–2.11 years) were included.

### Table 2 Summary of cases with complications

<table>
<thead>
<tr>
<th>Case nr.</th>
<th>Plate</th>
<th>Breed</th>
<th>Age (y)</th>
<th>Weight (kg)</th>
<th>FX type</th>
<th>Distal length (mm)</th>
<th>Distal ratio</th>
<th>Adjusted distal length (mm)</th>
<th>Adjusted distal ratio</th>
<th>Distal screw nr.</th>
<th>Post-op alignment</th>
<th>Bandage Failure method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5 Adapt</td>
<td>Miniature Pinscher</td>
<td>1</td>
<td>1.5</td>
<td>Short oblique</td>
<td>10</td>
<td>15%</td>
<td>N/A</td>
<td>N/A</td>
<td>2</td>
<td>Perfect</td>
<td>Splint 4 wk</td>
</tr>
<tr>
<td>2</td>
<td>1.5 Adapt</td>
<td>Toy Poodle</td>
<td>12.2</td>
<td>2.99</td>
<td>Short oblique</td>
<td>15</td>
<td>21%</td>
<td>N/A</td>
<td>N/A</td>
<td>2</td>
<td>Near anatomical</td>
<td>Splint (Time not recorded)</td>
</tr>
<tr>
<td>3</td>
<td>1.5 Adapt</td>
<td>Yorkshire Terrier</td>
<td>0.41</td>
<td>3.8</td>
<td>Short oblique</td>
<td>13</td>
<td>16%</td>
<td>15</td>
<td>21%</td>
<td>2</td>
<td>Near anatomical</td>
<td>Suture 3 wk Fracture through distal screw hole</td>
</tr>
<tr>
<td>4</td>
<td>2.0 LCDCP</td>
<td>Yorkshire Terrier</td>
<td>1.43</td>
<td>2.4</td>
<td>Short oblique</td>
<td>18</td>
<td>24%</td>
<td>N/A</td>
<td>N/A</td>
<td>2</td>
<td>Perfect</td>
<td>MRJ 2 wk</td>
</tr>
</tbody>
</table>

Abbreviations: FX, fracture type (CONFIRM); MRJ, modified Robert Jones bandage; N/A, not applicable; nr., number; post-op, postoperative.
weighing 4 kg or less (median: 2.46 kg, range: 2.36–4.0 kg) were treated for distal radial and ulnar fractures by two surgeons (AMS, MLH) and a surgical resident (AMA). One patient suffered bilateral radial and ulnar fractures and the fractures where evaluated separately for statistical analysis, for a total of seven radial and ulnar fractures in the 2.0-mm LC-DCP group. Breeds included Chihuahua (n = 3), Yorkshire terrier (n = 1), Maltese (n = 1), Terrier mix (n = 1) and Italian Greyhound (n = 1). The cause of fracture was reported to be a jump, fall, or drop from a height in five cases and other or unknown in two cases. There were three transverse and four short oblique fracture configurations.

The median diaphyseal width was 6 mm (range: 5–7 mm) and median distal segment length was 19 mm (range: 15–25 mm) with a median distal segment-to-total radius length ratio of 24% (range: 13–30%). Two patients were juvenile with open physes. No fracture repairs bridged the open physe in these patients. Removing the length of the open physe from the calculations reduced the effective plating length of the distal segment to a median of 17 mm (range: 15–25 mm). The new median distal segment ratio was 21% (range: 13–30%).

In one case in this group, the 2.0-mm LC-DCP was applied using 1.5-mm cortical screws, while 2.0-mm cortical screws were used in all the other fixations. The median length of the plates was six holes (range: 5–7 holes) with the median distal length two holes (range: 2–3 holes).

One author scored five patients as having perfect reduction and two with near-anatomical reduction. The second author scored two patients as having perfect reduction, four with near-anatomical reduction and one with less than 10% from perfect reduction. The median radiographic score averaged between the two observers at the first re-examination was 2.5 (range: 1.5–3) and 4 (range: 3.5–4) at the second re-examination.

Six of seven patients had a splint (n = 2) or modified Robert Jones bandage (n = 4) placed postoperatively for a range of 1 to 4 weeks. No complication was noted in the one patient without a bandage. Median follow-up including phone conversations was 3.68 months (range: 1.81–15.42 months).

There were not any minor complications for fractures repaired with the 2.0-mm LC-DCP. There was one major complication (►Table 2) reported. This patient (Case 4, 1.3 years old) re-fractured the antebrachium at some point between the 3-month follow-up and the 15-month evaluation for lameness. Radiographs revealed the fracture was healed in malunion with internal rotation, and caudolateral bowing (►Fig. 7). The patient was noted to have fair function and the owner declined a corrective osteotomy. The remaining six patients have radiographic evidence of full healing and physical examination findings of good (n = 1) or excellent (n = 5) outcome.

The distal segment length in the 2.0-mm LC-DCP group (median 19 mm) was significantly greater than that in the 1.5-mm Adaption group (12.5 mm; p = 0.0178). Also, the distal segment length adjusted for presence of an open physe in the LC-DCP group (median 17 mm) was greater than that in the 1.5-mm Adaption group (12 mm; p = 0.0073). Dogs with a 1.5-mm Adaption plate had significantly longer postoperative follow-up (median 5.85 months) than the LC-DCP group (3.68 months; p = 0.0048). There were not any significant differences in other variables analysed between the different plate groups.

Dogs with postoperative excellent limb function were less likely to have experienced a major complication than those with fair or poor limb function (OR = 0.012, 95% CI = 0.000, 0.362, p = 0.0224). There were not any significant relationships between complication outcome and the remaining predictors. While not significant (p = 0.0747), all major complications occurred in short oblique fracture configurations and more complications were observed in the 1.5-mm Adaption group (p = 0.1962).

Analysis of inter-observer variability revealed fair agreement in postoperative reduction scores between the authors.
The first re-examination radiographic scores showed slight agreement between the authors and the second re-examination scores had perfect agreement.

**Discussion**

The success rate of internal fixation of small breed radial fractures has been reported as 70 to 95%\textsuperscript{5,9,10} with overall complications in up to 68% of repaired fractures.\textsuperscript{11} The complication rate in this study was 50% for the 1.5-mm Adaption plates and 14.3% for the 2.0-mm LC-DCP.

The advent of locking plates has been beneficial for both human and veterinary medicine. These fixed angle constructs resist shear forces better than conventional constructs, and as such, are much less likely to fail by screw pull-out. They are also able to withstand higher axial loads, allowing for stronger fixation in potentially weaker bone.\textsuperscript{12} One of the 1.5-mm Adaption plates failed via either screw pull-out or fracture through a screw hole. It is noted that no locking screws were used in this construct. The use of locking screws may have prevented this failure. It was also noted that the immediate postoperative radiographs revealed the most proximal screw in the distal segment was closer to the fracture line than planned, which may have weakened the construct. It is also noted that since locking plates do not rely on compression of the plate to the bone, further preservation of the blood supply may be achieved.\textsuperscript{13}

This may be beneficial in small breed dogs, which have a decreased vascular density at the distal diaphyseal–metaphyseal junction.\textsuperscript{6}
A second Adaption plate fractured through the middle screw hole 3 months postoperatively. The patient was the smallest at 1.5 kg, had the smallest distal segment length at 10 mm, smallest distal segment ratio at 15% and tied the smallest diaphysis width at 5 mm. A five-hole Adaption plate with all locking screws was used. On review of the radiographs, the middle screw was not parallel to the other four, suggesting the screw was cross-threaded. The authors suggest that the cross-threading may have weakened the implant and contributed to failure at this location.

Two patients in each group were juvenile with open physes. The presence of an open physis decreased the total available distal segment length available for screw placement. While this may make surgery technically demanding, only one of these patients exhibited fixation failure (1.5-mm Adaption plate with fracture through distal screw hole).

All complications occurred in short oblique fracture configurations. While not significant ($p = 0.0747$), this result could be due to Type II error due to our small sample size. This is not unexpected since transverse fractures allow more load...
sharing between the bone and plate as compared with oblique fractures. The population of patients with fractures treated with a 1.5-mm Adaption plate had significantly shorter distal segment length. The Adaption plate has a higher screw hole per centimetre of plate density than the 2.0-mm LC-DCP. As such, it was chosen when it was determined to be too difficult to achieve a minimum of two screws in the distal segment with a different plate.

As the complication rates were not significantly different between the 1.5-mm Adaption plate and 2.0-mm LC-DCP groups, the authors accept the hypothesis that the two groups would have similar outcomes. The authors note that while not significant, the complication rate for the 1.5-mm Adaption plate was higher than that of the 2.0-mm LC-DCP. A post hoc power analysis was performed based on the current sample size \((n = 13)\) and the parameter estimates derived from the given dataset to determine the retrospective power of the observed effect (i.e., the relationship between complication and plate type). The post hoc power analysis was performed using Gpower version 3.1.9.2. Given the observed OR \((4.334)\), the probability of having complication under the treatment of a 1.5-mm Adaption plate, and the sample size \((n = 13)\), the power of observing a significant effect of plate type at the 0.05 level of significance \((\alpha = 0.05)\) was 0.1920, which is quite low. Care should be taken when making clinical decisions based on these results given the expected Type II error.

This study has limitations inherent to a retrospective study in addition to subjective outcome measurements, limited follow-up, variable locking-to-cortical screw ratios, multiple surgeons involved, limited case numbers and the comparison between a non-locking and locking plating system. While a significant limitation of this study is the low case numbers reported, the authors believe it provides useful clinical information to the surgeon in determining which fixation method to choose for a particular fracture. Future studies, including multi-institutional studies and the use of the 1.5-mm LCP are warranted to provide further details on the reliability and limitations of these plating systems. The authors attempted to improve the subjective scoring by having both authors score the postoperative reduction and follow-up radiograph scores; however, only fair inter-observer agreement was noted for reduction scores and slight agreement for the first radiograph recheck. Despite these findings, the authors still suggest the results are valid, as there was no evidence of a significant relationship between these scores from either author and postoperative complications. While it would be ideal to compare a 1.5-mm Adaption plate to the same design in a 2.0-mm size, such a plating system was not available at the authors' practice. Despite the limitations in this case series, the authors recommend that the 1.5-mm Adaption plate should only be used when a 2.0-mm LC-DCP would not allow for a minimum of two screws in the distal segment and at the discretion of the surgeon. Alternatively, other forms of fixation not evaluated in this study may be more appropriate. In cases where a 2.0-mm LC-DCP will fit adequately, the authors recommend the 2.0-mm LC-DCP over the 1.5-mm Adaption plate.

**Author Contributions**

All data acquisition and initial manuscript drafting was performed by Thomas Nelson. Both authors contributed to the conception of the study, study design, data analysis and interpretation, revising of the manuscript, and approval of the submitted manuscript.

**Conflict of Interest**

The authors declare that there is no conflict of interest.
References