ORIGINAL ARTICLE

Promising results after the treatment of simple and complex distal humerus type C fractures by angular-stable double-plate osteosynthesis

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KEYWORDS
Distal humerus fracture;
Osteosynthesis;
Angular-stable fixation;
Anatomically shaped;
Functional result;
Complications;
Perpendicular plating

Summary

Introduction: The aim of this study was to evaluate the functional results and complications following open reduction and internal fixation of distal humerus type C fractures (AO classification) using an anatomically precontoured, angular-stable double-plate system.

Patients and methods: The study is a retrospective analysis of 45 patients with 46 type C fractures. There was one C1, eight C2 and 31 C3 fractures. Twelve fractures were open (Gustilo classification). Follow-up was performed on 38 patients with 39 fractures (84%) after 14 months (range, 12–22). The mean age was 50 years (range, 14–87). Functional results were evaluated using the Mayo Elbow Performance Score (MEPS); the Disabilities of the Arm, Shoulder and Hand score (DASH); and range-of motion (ROM) measurements. Complications were classified as minor or major, and the postoperative and follow-up X-rays were analyzed.

Results: Thirty-four fractures were considered stable to allow early physical therapy. With a mean MEPS of 85 points, 36 results (36/39 [92%]) were rated as excellent or good. The mean DASH was 22.5 points, and the ROM for extension-flexion was 105° (range, 50–145). Sixteen major complications (eventually coexistent: 6 × implant failure, 3 × non-union, 6 × stiffness, 2 × necrosis capitulum, 4 × failure olecranon osteotomy refixation) and two minor complications were recorded in 17 patients. These adverse events led to 14 revision surgeries (14/39 [36%]). Except for extension deficit, no statistically significant differences were found between the articular simple and articular complex fractures and when comparing the results between patients with and without a major complication.

Conclusion: The anatomically precontoured and angular-stable double-plate system provides sufficient immediate postoperative stability to allow early physiotherapy, even in C3-type fractures. Excellent or good results could be achieved in the vast majority of patients, independent

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on having suffered a complication or not. Complication rates were remarkably high, emphasizing the difficulties associated with this rare type of fracture.

Level of evidence: Level IV Retrospective study.
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Introduction

Fractures of the distal humerus are rare and account for only about 2% of all fractures in mature patients [1]. Due to their low frequency, these types of fractures remain one of the most problematic joint fractures treated by orthopedic and trauma surgeons, and osteosynthesis is challenging, particularly when osteopenia and multifragmentary fractures are present. Surgeons will be faced with an increasing incidence of this type of fracture. Based on the trends observed between 1970 to 2007 in the 60-year-old and older female population in Finland, Palvanen et al. calculated the number of distal humeral fractures to be three-fold higher in 2030 than in 2007 [2]. In addition, treatment of these patients is complicated by a poor tolerance of joint immobilization [3-6]. However, satisfactory results can be obtained when anatomical reduction and stable osteosynthesis is possible and when physiotherapy can be initiated early after treatment [3,7-12]. Consequently, open reduction and internal fixation (ORIF) is accepted as the gold standard in the treatment of intra-articular distal humerus fractures. It is well accepted, that plates should be placed at both columns in type C fractures. Yet, there is no consensus concerning the orientation of the plates at the columns [13,14]. Nevertheless, complication rates up to 35% emphasize the difficulties in treating these fractures [3,15]. The lack of stability and the complex anatomy of the distal humerus led to the development of anatomically pre shaped implants that provide good clinical results, although complication rates remained considerably high [16-20].

The introduction of angular-stable implants revolutionized the operative treatment of many fractures at different anatomic sites, particularly in situations with multifragmentary and osteopenic fractures. Using these implants, the stability of the osteosynthesis no longer relies on the friction between the underlying bone and the plate resulting from screw torque but rather uses a single-beam construct that converts shear stress into compressive stress [21,22]. The periosteal blood supply is preserved by acting as an internal fixator [23,24].

Angular-stable reconstruction plate osteosynthesis at the distal humerus was first described by Konner et al. in 2003 [25], and some biomechanical studies were able to demonstrate the advantages of these implants [4,26].

Recently, anatomically pre contoured and angular-stable implants with extensive distal screw options for double plate osteosynthesis such as the locking compression plate (LCP) distal humerus plate system (LCP DHP, Synthes, Umkirch, Germany) were introduced, promising enhanced stability in complex fractures and an ease in application. Biomechanical studies have proven the advantages of these implants, particularly in reduced bone quality [4,26-28]. Good clinical results were reported in few reports, most of which involved only small numbers of patients [26-32].

There is still controversy concerning the value and proper indications for the use of locking plate systems in the treatment course of distal humerus fractures. To date, there are no studies comparing conventional plate and angular-stable plate osteosynthesis. Even though there is a lack of available evidence in support of locking plates, it is believed that their use may be advantageous in complex intra-articular fracture patterns. This is particularly true in patients with limited bone quality [13]. The purpose of this study was to evaluate our functional results and the complications after osteosynthesis of distal humerus Arbeitsgemeinschaft für Osteosynthesefragen/orthopedic trauma association (AO/OTA) type C fractures with the latest generation angular-stable and anatomically pre shaped implant (LCP distal humerus plate system, Synthes, Umkirch, Germany). The results were analyzed for intra-articular simple vs. complex fracture types. It was our null hypothesis, that the functional results were not significantly different.

Patients and methods

In a 50-month-period, 54 mature patients with 55 type C distal humerus fractures based on the AO/OTA classification [33] were treated consecutively at our institution. Out of these patients, two were treated conservatively, and five were treated by primary total elbow arthroplasty (TEA). All patient with a closed or open type C fracture who confirmed written and informed consent (according to the Declaration of Helsinki) were included. Patients with pathologic fractures (excludes osteopenic fracture), pre-existing limitations of range-of-motion, ipsilateral complex fracture of the olecranon (type Schatzker B/D/F [34]), ipsilateral fracture of the radial head (type Mason II/III [35]) and ipsilateral palsy were excluded. Therefore, two patients were excluded from the study.

As a result, the study was based on the remaining 45 patients with 46 fractures. All of them were treated with the LCP distal humerus plate system (LCP DHP, Synthes, Umkirch, Germany). Six of these patients were lost to follow-up (two died due to causes not related to the fracture, and four were not available). As a result, the study cohort comprised 39 patients with 40 fractures of the distal Humerus. The study protocol was reviewed and approved by the institutional review board of the department involved.

One patient included in the study cohort was excluded from the follow-up cohort because he suffered an osteosynthesis failure and was converted to total elbow arthroplasty as a salvage procedure. This patient was rated as to have suffered a major complication. As a result, final functional assessment was carried out in 38 patients with 39 fractures (38/45 [84%]) after a mean of 14 months (range, 12-22 months).

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Angular-stable osteosynthesis in articular distal humerus fractures

The mean age of the 18 men and 21 women was 50 years (range, 14–87 years). Age distribution was found to be as 12 patients 14 to 40 years, nine patients 41 to 50 years, seven patients 51 to 60 years, 10 patients 61 to 70 years and two older than 70 years. The dominant arm was involved in 18 fractures (18/39 [46%]).

Fractures were classified using the AO/OTA classification system [33] on the basis of preoperative X-rays, CT scans and intraoperative findings. A type C1 simple intra-articular fracture was found in one patient (1/40 [2.5%]), and type C2 simple articular fractures with metaphyseal comminution were seen in eight cases (8/40 [20%]). Thirty-one fractures (31/40 [77.5%]) were classified as C3 multifragmentary intra-articular fractures. Open fractures were present in 12 cases (eight type I (8/40 [20%]) and 4 type II (4/40 [10%]) using the Gustilo classification [36] (Table 1).

Posttraumatic neurological deficits were diagnosed in six patients (6/39 [15.4%]); three involved the ulnar nerve and three the radial nerve.

Seven patients had concomitant injuries of the involved upper extremity (three fractures of the radial head, two fractures of the olecranon and two fractures of the distal radius).

The majority of fractures (35/40 [87.5%]) were treated using definitive ORIF after 1 day (range, 0–15), while five open fractures were primarily treated by debridement and external fixation due to the compromised soft tissue conditions.

For the surgical procedure, the patients were placed in the prone position with the involved arm resting on a bench that allowed at least a 90° flexion, and an intravenous antibiotic was applied. In all patients, a dorsal approach was performed. Visualization of the fracture using the triceps-on approach (Alonso-Llamas) was performed in five patients, while in the remaining cases (33/40 [82.5%]), a chevron osteotomy of the olecranon was performed. The accompanying olecranon fracture was used two times (2/40 [5%]) for visualization. The ulnar nerve was explored routinely; however, transposition was only performed in three patients were a mechanical irritation at the ulnar plate was a concern.

After temporary reduction and fixation with K-wires, osteosynthesis using the LCP distal humerus plate system (LCP DHP, Synthes, Umkirch, Germany) was performed. A double-plate osteosynthesis in perpendicular fashion with a medial plate and a dorsolateral plate was completed. The articular fracture fragments were fixed with angular-stable 2.7-mm titanium screws, and the plates were fixed to the shaft using conventional cortical 3.5-mm screws. Impingement during extension was excluded intraoperatively. For osteosynthesis of an olecranon fracture or osteotomy, screws (1/35 [2.8%]), angular-stable plates (2/35 [5.7%]) or a custom-made one-third tubular hook plate (32/35 [91.5%]) was used. In the study cohort, eight surgeons performed the 40 osteosynthesis at the distal humerus.

The elbow was splinted in 90° flexion postoperatively, and the drain was removed 24 to 48 h post-surgery. If osteosynthesis was considered stable under visual control intraoperatively in the full arc of motion, assisted physical therapy without ROM restrictions was initiated. A primary stable osteosynthesis allowing early physiotherapy was obtained in 34 fractures (34/40 [85%]). Due to the fracture morphology, non-compliance and/or osteopenia, additional immobilization was carried out using a cast in four patients (4/40 [10%], 10 to 28 days) and an external fixator in two patients (2/40 [5%], 4 and 6 weeks).

The functional outcome was evaluated using the Mayo Elbow Performance Score (MEPS) [37]; the Disabilities of the Arm, Shoulder and Hand score (DASH) [38,39]; and range-of-motion (ROM) [40] measurements performed with a goniometer at the earliest 12 months after the index procedure or revision surgery. The postoperative and follow-up X-rays were analyzed. Heterotopic ossifications (HO) were classified according to the rating system introduced by Hastings [41]. Grade I HO without ROM limitations, grade IIa with limitations in the extension-flexion plane, grade IIb with limitations in the pronation-supination plane and grade IIc with limitations in both planes. Grade III HO represents ankylosis of the joint.

Complications were recorded and classified as minor and major. A complication was considered major when surgical revision was necessary (even if the patient refused surgery) or if significant impairment resulted. Failed osteosynthesis at the distal humerus or following olecranon osteotomy refixation, non- and mal-union, necrosis of the capitulum or trochlea as well as significantly limited range-of-motion were judged as a major complication. Delayed union or isolated screw loosening (without further signs of instability) was rated as a minor complication.

The functional results (MEPS, DASH, ROM) and complications were compared between the AO subgroups (simple articular vs. complex articular) and in dependence of having suffered a complication or not. Using the Shapiro-Wilk test, all outcome measures were found to follow a non-normal distribution. Subsequently, the Mann–Whitney U test was used to evaluate the differences between the groups. The results are presented as the median, minimum and maximum. Nominal variables were tested by Fisher’s exact test. A level of $P \leq 0.05$ was considered significant, and all tests were two-sided. SPSS 18.0 software was used for statistical analyses (SPSS Inc., Chicago, Illinois, USA).

<table>
<thead>
<tr>
<th>Group</th>
<th>n (fractures)</th>
<th>Age (years)</th>
<th>Mean (range)</th>
<th>Open (I/II) (Gustilo classification)</th>
<th>Dominant</th>
<th>Men:Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1/2.5%</td>
<td>58</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1:0</td>
</tr>
<tr>
<td>C2</td>
<td>8/20%</td>
<td>35.6 (14–66)</td>
<td>2 (1/1)</td>
<td>5</td>
<td>3:5</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>31/77.5%</td>
<td>53 (20–87)</td>
<td>10 (7/3)</td>
<td>13</td>
<td>14:16</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>40/100%</td>
<td>50 (14–87)</td>
<td>12 (8/4)</td>
<td>18</td>
<td>18:21</td>
<td></td>
</tr>
</tbody>
</table>

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Table 2: MEPS results based on Arbeitsgemeinschaft für Osteosynthesefragen/orthopedic trauma association (AO/OTA) subgroups.

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 and 2 (n = 9)</td>
<td>5</td>
<td>4</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>C3 (n = 30)</td>
<td>13</td>
<td>14</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total (n = 39)</td>
<td>18</td>
<td>18</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3: Functional outcome and complications based on subgroup.

<table>
<thead>
<tr>
<th>Measurea</th>
<th>Articular simple (C1&amp;2)(9/39 [23%])</th>
<th>Articular complex (C3)(30/39 [77%])</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEPS</td>
<td>100 (range, 75–100)</td>
<td>85 (range, 50–100)</td>
<td>0.460</td>
</tr>
<tr>
<td>DASH</td>
<td>5.8 (range, 0–58)</td>
<td>22.5 (range, 0–65.8)</td>
<td>0.24</td>
</tr>
<tr>
<td>Extension deficit</td>
<td>10° (range, 0–40)</td>
<td>20° (range, 0–40)</td>
<td>0.033b</td>
</tr>
<tr>
<td>Flexion</td>
<td>125° (range, 90–145)</td>
<td>125° (range, 50–140)</td>
<td>0.857</td>
</tr>
<tr>
<td>ROM (Ex/Flex)</td>
<td>100° (range, 80–145)</td>
<td>105° (range, 50–140)</td>
<td>0.46</td>
</tr>
<tr>
<td>Minor complications</td>
<td>1</td>
<td>1</td>
<td>0.404</td>
</tr>
<tr>
<td>Major complications</td>
<td>1</td>
<td>11</td>
<td>0.233</td>
</tr>
</tbody>
</table>

Results

The vast majority of patients achieved excellent (18/39 [46.2%]) and good (18/39 [46.2%]) results, according to the MEPS (Table 2 and Fig. 1). Two patients were rated as fair and one as poor. The mean overall MEPS was 85 points (range, 50–100). Concerning the MEPS, no significant differences were found between the subgroups. The dependence of the MEPS on the fracture subgroup is displayed in Table 3.

The mean overall DASH Score was 22.5 points (range, 0–65.8) and was not statistically different between the groups. Full extension was found in 6 patients, whereas a mean extension deficit of 20° (range, 5–40) was identified in the remaining patients. Extension was significantly impaired in C3 fractures (P = 0.033). The mean flexion was 125° (range, 80–145) and was not statistically different between the subgroups. The mean ROMs for extension-flexion and pronation-supination were 105° (range, 50–145) and 170° (range, 95–180), respectively; these values were not significantly different between the subgroups (Table 3).

Sixteen major and two minor complications were recorded in 17 patients (17/39 [43%]) which led to 14 revision surgeries (14/39 [36%]). The patient with a bilateral fracture suffered complications on both sides. Implant failure at the distal humerus occurred in six cases (6/39 [15.4%]), resulting in revision surgery in five of the six patients; one patient refused revision surgery. The failure mode was a secondary fragment or screw dislocation in the capitellum region in four cases and plate breakage at the ulnar column in one case (Fig. 2).

Non-union at a supracondylar level that necessitated autogenous bone grafting was identified in three fractures (3/39 [7.7%]). Necrosis of the capitulum was present in two patients (2/39 [5.1%]). As part of the complication management, 14 patients underwent repeat surgery with screw exchange, plate replacement and/or bone grafting (14/39 [36%]). One of these patients with an osteopenic C3 fracture was treated by total elbow arthroplasty as a salvage procedure and rated as to have suffered a major complication. However, he was excluded from the functional follow-up cohort (Fig. 2). Six patients underwent open arthrolysis and/or resection of heterotopic ossifications for the impairment of extension-flexion ROM (6/39 [15.4%]).

Concerning major complications, statistically significant differences were not found between the articular simple and complex groups. The distribution of the major complications to age groups is displayed in Fig. 3.

Out of the six patients (6/39 [15.4%]) with posttraumatic sensory neurological deficits, two resolved until follow-up. Three patients (3/39 [7.7%]) had postoperative sensory neurological deficits (1 × N. ulnaris, 2 × N. radialis), of which two disappeared completely until follow-up.

Failure of the osteosynthesis after olecranon osteotomy occurred in four patients (4/39 [11.4%]), necessitating revision surgery in all of them.

Interestingly, at final functional assessment no significant differences were found when comparing the results between patients with and without a major complication (Table 4).

Discussion

Open reduction and internal fixation is widely accepted as the treatment of choice for distal humerus fractures, even in elderly patients with comminution and osteopenia [6,9,11,42–44]. Even though satisfactory results were reported, complication rates remain remarkably high [3,45,46]. In a retrospective clinical study, Korner found implant failure represented by screw loosening or plate breakage in 27% of patients. In six out of seven patients, distal screw loosening occurred at the radial column [3]. Similar findings were presented by Södergard, who found osteosynthesis failure in 29.5% of 61 consecutive patients, 2013). http://dx.doi.org/10.1016/j.otser.2013.02.004

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Angular-stable osteosynthesis in articular distal humerus fractures

Figure 1 Sixty-one-year old male: a: CT, AO type 13 C3; b: result after osteosynthesis with the locking compression plate distal humerus plates (LCP DHP system); c: range-of-motion after 20 months, Mayo Elbow Performance Score 100 points.

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Figure 2  Eighty-year-old female: a: anterior-posterior and lateral X-ray, AO 13 C3, pre-existing osteopenia; b: postoperative control, early dorsoradial fixation failure with anterior dislocation of the capitulum. Dotted circle: anatomic location; continuous circle: dislocated capitulum; c: anterior-posterior and lateral X-ray after conversion to total elbow arthroplasty (Coonrad/Morrey total elbow, Zimmer).

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which makes the initial unstable osteosynthesis responsible in 20% of the cases [15].

The outstanding importance of stable fracture fixation and early physiotherapy was emphasized by Papaioannou, who found that functional results were significantly improved when stable fixation was achieved [11]. Accordingly, Korner found a significant impairment in the range-of-motion if immobilization was carried out longer than 15 days [3]. Those findings were supported by Charissoux, who found fair and poor results in 87% of those patients who didn’t obtain early physical therapy [12]. Similar results were presented by Proust, who found the Morrey score reduced when immobilisation was needed [47].

The ability to compare our clinical results to the results of other studies is limited because there are few reports dealing with the same implant and because of differences in the study cohorts distribution and fracture [29—31] (Table 5).

Our functional results based on the MEPS were excellent or good in 92% of patients. We found no significant differences in the MEPS with respect to the AO subgroups. Our

<table>
<thead>
<tr>
<th>Measure</th>
<th>Without complication (25/39[64%])</th>
<th>With major complication (14/39[36%])</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEPS</td>
<td>92.5 (range, 75–100)</td>
<td>85 (range, 60–100)</td>
<td>0.176</td>
</tr>
<tr>
<td>DASH</td>
<td>13.75 (range, 0–65.8)</td>
<td>30 (range 0–64.2)</td>
<td>0.291</td>
</tr>
<tr>
<td>Extension deficit</td>
<td>17.5 (range, 0–40)</td>
<td>15 (range, 0–40)</td>
<td>0.897</td>
</tr>
<tr>
<td>Flexion</td>
<td>125 (range, 90–145)</td>
<td>125 (range, 50–140)</td>
<td>0.919</td>
</tr>
<tr>
<td>ROM (Ex/Flex)</td>
<td>105 (range, 55–145)</td>
<td>100 (range, 50–140)</td>
<td>0.828</td>
</tr>
</tbody>
</table>

Table 4 Differentiation of final functional results between patients without and with major complications.

<table>
<thead>
<tr>
<th>Author</th>
<th>N</th>
<th>Age</th>
<th>Distribution of fractures</th>
<th>FU</th>
<th>Angular-stable/Configuration</th>
<th>MEPS</th>
<th>Result</th>
<th>Excellent/good</th>
<th>Fair/poor</th>
<th>Re-OP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanchez-Sotelo et al., 2007 [48]</td>
<td>34</td>
<td>58</td>
<td>A3 9% C2 15% C3 76%</td>
<td>24</td>
<td>No, double plate 180º</td>
<td>85</td>
<td>80%</td>
<td>20% (7)</td>
<td>20% (9)</td>
<td></td>
</tr>
<tr>
<td>Athwal et al., 2009 [17]</td>
<td>32</td>
<td>56</td>
<td>C1 9% C2 28% C3 63%</td>
<td>27</td>
<td>No, double plate 180º</td>
<td>82</td>
<td>69%</td>
<td>31% (10)</td>
<td>31% (10)</td>
<td></td>
</tr>
<tr>
<td>Proust et al., 2007 [47]</td>
<td>36</td>
<td>78</td>
<td>C1 22% C2 28% C3 50%</td>
<td>35</td>
<td>No, various implants and configurations</td>
<td>73</td>
<td>58%</td>
<td>42% (15)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Korner et al., 2005 [3]</td>
<td>45</td>
<td>73</td>
<td>A2 9% A3 16% B2 4% B3 7% C1 16% C2 20% C3 29%</td>
<td>24</td>
<td>No, 73% double plate 90º</td>
<td>83</td>
<td>57%</td>
<td>43% (19)</td>
<td>16% (7)</td>
<td></td>
</tr>
<tr>
<td>Greiner et al., 2008 [30]</td>
<td>12</td>
<td>55</td>
<td>B2 8% B3 8% C1 17% C2 34% C3 43% C3 100%</td>
<td>10</td>
<td>Yes, 90º</td>
<td>91</td>
<td>83%</td>
<td>17% (2)</td>
<td>8% (1)</td>
<td></td>
</tr>
<tr>
<td>Rübergerd et al., 2008 [31]</td>
<td>11</td>
<td>44</td>
<td>B1 5% B2 2% C1 18% C2 15% C3 60%</td>
<td>15</td>
<td>Yes, 90º</td>
<td>81</td>
<td>73%</td>
<td>27% (3)</td>
<td>18% (2)</td>
<td></td>
</tr>
<tr>
<td>Reising et al., 2009 [29]</td>
<td>40</td>
<td>60</td>
<td>B1 5% B2 2% C1 18% C2 15% C3 60%</td>
<td>11</td>
<td>Yes, 90º</td>
<td>85</td>
<td>73%</td>
<td>27% (11)</td>
<td>15% (6)</td>
<td></td>
</tr>
<tr>
<td>Own study</td>
<td>40</td>
<td>50</td>
<td>C1 2% C2 20% C3 78%</td>
<td>14</td>
<td>Yes, 90º</td>
<td>85</td>
<td>92%</td>
<td>8% (3)</td>
<td>36% (14)</td>
<td></td>
</tr>
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Table 5 Functional results and revision rates following osteosynthesis of distal humerus fractures taking the type of implant fixation and orientation into consideration.
results among all type C fractures were slightly superior to those reported in the recent literature. In the studies by Greiner et al. and Reising et al., good and excellent results were found in 83 and 73% of the patients, respectively [29,30]. The complication rates in those studies were fortunately lower than in ours. Greiner et al. found one non-union following olecranon osteotomy (8%) in the 12 patients available for follow-up. Reising et al. reported on six revision surgeries (15%) in 45 patients. It needs to be stated, that the percentage of C3 fractures in those studies was lower than in the study presented (43 and 60% versus 78%). Rübben et al. found that 73% patients with C3 fractures showed good and excellent results but as in our series the complication rate is high. They suffered fixations failure in two and planned surgical release in another two patients, resulting in 36% of revision surgeries [31] (Table 5).

The mean DASH score in our study was 22.5 points, with no significant differences between the subgroups. These results differ from those found by Rübben et al., who analyzed 11 patients with C3 fractures with a mean score of 51 points [31]. An explanation of the difference might be the learning curve with this new device, which also led to a higher incidence of complications in the primarily treated patients in our series. Also only C3 fractures were included in this series.

There are remarkable differences between our results and those achieved with conventional double-plate osteosynthesis. Good or excellent results in the C3 subgroup were achieved in only 26% of the cases in the study by Korner, whereas in our series, 90% obtained good or excellent results [3]. These findings might be caused by the reduced need for prolonged immobilization due to the improved screw anchorage in angular-stable implants. However, it must be stated that the mean patient age was somewhat higher in the series reported by Korner. In another report, good and excellent results were reported in 81% of the cases, although the overall re-operation rate was 38.4% [44]. Similar findings were reported by Athwal et al. using conventional parallel plating with anatomical preshaped implants, in which good and excellent results were achieved in 69% of patients. Complications were found in 53% of the patients requiring revision surgery in 31%. In this study C3 fractures comprised 63% [17]. Unfortunately, subgroup analyses were not performed [15] (Table 5). Rebuzzi et al. found excellent results in 84% using the same implant, although there were 54% type A and only 15% C3-type fractures in their cohort [18].

In our series, we found a mean ROM for extension/flexion of 105° (range, 50-145). With 170° (range, 95-180), forearm rotation was almost uncompromised, which is consistent with data reported by other authors. The limited extension was significant between the subgroups, with a greater deficit in the articular complex group. Theoretically, olecranon osteotomy and subsequent osteosynthesis might contribute to this finding. However, the rate of olecranon osteotomies between the subgroups was not statistically different (P = 0.188). Interestingly, no further differences between the subgroups were identified. The ROM measured in this study should provide the majority of patients with the ability to perform daily activities. Morrey reported the golden arc of motion to be 100° (0-30-130°), and Raiss recently found the daily ROM in 10 activities measured with infrared light-reflecting markers to be 110° (0-36-146°) [49,50].

We found a high overall complication rate of 43% and a revision rate of 36% in this study. However, at final functional follow-up, the results were good to excellent in the majority of patients even after revision surgery. Total elbow arthroplasty might be a valuable option in elderly and compliant patients. Early results are encouraging but there is a lack of experience for the long-term results [13]. Gambirasio evaluated the functional and radiological results of 10 patients treated by total elbow arthroplasty with a follow-up of 2 years [51]. He found good functional results in all and radiolucent lines at the humeral stem in 20% of the patients. Kamineni reported on results in 49 fractures treated by primary total elbow arthroplasty in patients with a mean age of 69 and a mean follow-up of 7 years [52]. In all the 43 patients followed-up for at least 2 years, he found good results in the Mayo Elbow Performance Score. However, revision surgery was needed for wound or prosthesis associated complications in 23%. In contrast to posttraumatic osteoarthritis, which is often less symptomatic at the elbow, loosening or infection of a prosthesis are serious complications often necessitating extensive revision surgery. Considering the demographic change in the population, the need for implant survival for at least 10 years must be expected. In future studies with longer follow-up intervals an increase of complications must be expected. In addition, the lifelong limitation to lift weights more than 5 pounds seems to be a severe restriction particularly for younger aged patients. To date, only one prospective-randomized study compared total elbow arthroplasty with open reduction and internal fixation using plates [53]. After a follow-up of 2 years McKee found improved outcomes and lower complication rates in the arthroplasty cohort.

Complications related to fixation failure represented by secondary dislocation of distal fragments in 15% of the
patients were common in our study. We agree with the statement by Athwal that the high complication rate is not associated with the implant used but rather results from the complexity of the fracture [17]. However, as reported previously, fixation failure is more likely to occur laterally in the distal fragment than medially [3,54]. There are biomechanical studies that support these observations. Concordantly, Diederichs and Park reported the lowest bone mineral density in the capitellar region at the distal humerus in their radiological studies [2,59], and Dunham found inferior indentation modulus and strength values in the posterior lateral region [56]. Additionally, the in-vivo forces around the elbow are rarely known. In our opinion, there are rotational forces besides extension-flexion and valgus-varus forces that affect distal fracture fragments. Internal rotational forces at the distal fragments, as excited when the elbow is flexed and forearm is orientated horizontal, might result in a force vector in the same orientation as the dorsoradial screws, making anterior displacement of the capitulum likely (Fig. 2). Therefore, we now use the dorsolateral plates with lateral support, which allow the insertion of two additional screws extending from lateral to medial. Currently, it is not known whether recently introduced implants with poly-axial screw options for distal fragment fixation can improve screw anchorage. Therefore, further biomechanical and clinical studies are desirable. It is also up to debate whether to use double-plate osteosynthesis in a parallel or perpendicular fashion. Some biomechanical studies strongly suggest parallel configuration to be superior in type A3.3 and C2 fractures, but a significant clinical difference in terms of function and bony union was not detected, rendering double plate osteosynthesis in either form a grade B recommendation [13,14,28,57–59].

A delayed union or non-union of the distal humerus was found in five patients, making bone grafting necessary in three of them. In agreement with other reports in the literature, we detected non-union exclusively at the supracondylar level rather than the intercondylar level [54,60,61]. The region of the olecranon fossa is known to be a watershed area, and iatrogenic injury to the blood supply must be avoided [62,63]. As a result of the non-union, plate breakage at the ulnar column occurred in one of our patients. Plate breakage secondary to fatigue due to non-union is well known [21,64]. A similar case with radial plate breakage in a non-union was reported by Rübbenrdt, but plate bending was found to be responsible [31]. Angular-stable osteosynthesis is regularly carried out in a hybrid fashion with angular-stable fixation of the articular fragments and conventional fixation of the articular block to the shaft. Thus, bending of the implant is required. To avoid weakening the plate, bending should not be performed in the long hole of the plate. We want to emphasize that, despite the introduction of new implants, the principles of osteosynthesis must be recognized. Additionally, fracture gaps at the supracondylar level must be avoided because the stiffness of the implant-bone-construct prevents bone contact and prohibits the formation of callus [21]. In situations with significant bone loss, autografting or shortening must be considered [65]. Nevertheless, stability of the osteosynthesis seems to be of utmost importance since Proust found humeral non-union in 32% of the patients treated and in 78% of the non-unions fixation was not considered to be stable by the authors [47].

The high incidence of approach-related complications is alarming. However, the chevron osteotomy is the standard approach in articular fractures, particularly C3 fractures. Wilkinson measured the amount of visible articular surface, comparing the triceps-splitting, triceps-sparing and chevron-osteotomy approaches, and found the visible surface to be improved by 20% and 40% by the triceps-sparing and chevron-osteotomy approaches, respectively [66]. Treating olecranon fractures with the one-third tubular hook plate yielded excellent results, even in comminuted fractures [26]. We do recognize the limitations of our study. The retrospective nature of the study and the rarity of the fracture result in heterogenic subgroups. Additionally, a selection bias could not be excluded because not all patients with distal humerus fractures in our institution were treated by ORIF. Unfortunately not all patients were available for a final follow-up. However a follow-up quote of 85% seems to be adequate. Final functional assessment was performed after a mean of 14 month. Since all fractures were united to this date, further fracture or implant related complications seem to be unlikely. Yet, since degenerative changes will increase over time, a functional assessment to a later date is desirable. Although the range-of-motion measurement taken with a handheld goniometer is known to have an inaccuracy, this was controlled by having all measurements performed by the same person (SH) with the same instrument [40]. Statistical evaluation was limited due to the small sample size and the heterogeneity of the subgroups. However, on the basis of our data, we conclude that even if suffering complication angular-stable fixation of the distal humerus can lead to excellent or good clinical results in the majority of patients, even in those with complex articular fractures. Although there is no evidence based on this study it seems that the threshold of fractures which can be stabilized, particularly the multifragmentary with diminished bone quality, is raised.

Conclusion

Open reduction and internal fixation of distal humerus fractures with angular-stable, anatomically precontoured implants yield excellent or good results in the majority of patients, even those with C3 fractures. Even in elderly patients it should be considered the treatment of choice. Nevertheless, 43% of the patients suffering a major or minor complication necessitating revision surgery in 36% of them is worrisome, emphasizing the difficulties associated with these rare and complex fractures. Fortunately, we found no significant differences in patient with and without a complication in the treatment course. Prospective randomised trials will be necessary to clarify whether orthogonal or perpendicular angular-stable plating is superior in treating complex articular distal humerus fractures.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.
References


Angular-stable osteosynthesis in articular distal humerus fractures


