Less invasive polyaxial locking plate fixation in periprosthetic and peri-implant fractures of the femur—A prospective study of 41 patients

Steffen Ruchholtz, Bilal El-Zayat, Dimitri Kreslo, Benjamin Bücking, Ulrike Lewan, Antonio Krüger, Ralph Zettl

Department of Trauma, Hand and Reconstructive Surgery, University Hospital Marburg, Baldingerstrasse, 35043 Marburg, Germany

Department of Orthopaedics and Rheumatology, University Hospital Marburg, Baldingerstrasse, 35043 Marburg, Germany

A R T I C L E   I N F O

Article history:
Accepted 27 October 2012

Keywords:
Polyaxial locking plate
Periprosthetic hip fracture
Periprosthetic knee fracture
Minimally invasive surgery
Mini-open surgery
Peri-implant fracture
Proximal femur fracture

A B S T R A C T

Background: A great variety of methods for the stabilisation of periprosthetic fractures around total hip (THA) or total knee arthroplasty (TKA) have been described. We present the data of our experience in combining a polyaxial, anatomical locking plate with a standardised less invasive technique in the treatment of periprosthetic and peri-implant (femoral nail) femur fractures in this prospective study. Patients and methods: A consecutive series of 41 patients (33 women; age 79.8 ± 11 years) with 41 fractures (n = 17 periprosthetic THA, n = 10 periprosthetic TKA, n = 3 interprosthetic, n = 11 perinail) was treated in a ‘mini-open’ (MO; direct reduction of the fracture and percutaneous plate fixation in two-part fractures, n = 22) or a ‘minimally invasive’ (MI; indirect reduction and percutaneous fixation, n = 19) technique. All patients were followed up for 12 months postoperatively.

Results: The polyaxial locking mechanism allowed for the setting of a mean of 5.3 screws around an intramedullary implant. Supported by the less invasive strategy, mainly long plates (n = 36; 88% were longer than 24 cm) were applied without relevant soft-tissue complication. Five surgical revisions (12.1%) had to be performed. During the first postoperative stay, one seroma was evacuated and in two cases the plate broke due to failed biological healing 6 months after the MO technique. In one case, a revision prosthesis had to be implanted due to ligamentous instability, and in another case, soft-tissue balancing of the patella was performed. In the MO group, four of the five complications requiring surgical revision were seen. There was no infection. No statistical difference was seen between the MO and the MI groups for operating room (OR) time and perioperative need for transfusion. In patients with a poor state of health (n = 8; immobile and Glasgow Coma Outcome Scale = 3), no local complications were seen. All fractures in the peri-implant fracture group (n = 11) healed uneventfully.

Conclusion: Periprosthetic fracture fixation can be performed as part of a standardised less invasive strategy, but the MI technique should be the preferred treatment. The NCB system allows for a stable plate fixation around an intramedullary implant. With the less invasive technique, long plates can be applied with low rates of soft-tissue complication and implant failure.

© 2012 Elsevier Ltd. All rights reserved.

Introduction

In an ageing population with prolonged life expectancy, there will be an increasing demand for joint arthroplasty for osteoarthritis or femoral neck fractures. In Germany about 300,000 primary hip and knee arthroplasties due to arthrosis and 100,000 arthroplasties after femoral neck fracture are performed every year.1 At the same time, the incidence for revision surgery after joint replacement increases. About 25,000 revisions of hip arthroplasties and more than 10,000 revisions of knee arthroplasty surgeries are performed with an annual increase of about 10% in Germany.1 The incidence of periprosthetic fractures (PPFs) after knee and hip arthroplasty amounts to up to 2.5% and increases to 38% after revision surgery.3–7

Because of the high complication rate along with the need for early mobilisation, non-operative treatment of PPFs of the femur cannot be recommended for aged patients in most of the cases.8

On the other hand, even in the recent literature, important complication rates up to 41% and revision rates up to 29% are reported for surgical treatment of PPFs.9–14

0020–1383/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.injury.2012.10.035
Various reasons may account for possible postoperative problems:

- Bone quality is poor due to underlying osteoporosis.
- Stable fixation is difficult to achieve in areas with an intramedullary implant.
- Fracture healing is significantly delayed in aged patients.\textsuperscript{15}
- Prosthesis loosening may precede the fracture.

Surgical strategies are directed by the question of whether the prosthesis is stable. In a loose prosthesis, exchange for a revision prosthesis is commonly the treatment of choice.\textsuperscript{16,17} In these situations, the fixation of the revision implant has to be secured by long stems or a mega (tumour-)prosthesis that are well fixed in the diaphysis of the femur.

In stable implants, the primary strategies aim for fracture stabilisation, leaving the original prosthesis in place. To date, a variety of strategies for fracture fixation have been described. The results of conventional non-locking implants have been mostly poor with complication rates up to 53%.\textsuperscript{5} Therefore, today, monaxial locking plates are strongly recommended in complicated osteoporotic fractures. Although this offers a more stable fixation, the complication rates still remain high with up to 29% failure.\textsuperscript{5-14}

As monaxial plating systems are sometimes difficult to fix in regions with an intramedullary implant, additional devices such as cerclages are recommended to provide stable fixation. Historically, it has been suggested that the open technique in combination with cerclage may lead to a strangulation of periosteal vascularisation, resulting in bone necrosis and non-union.\textsuperscript{18-20} However, cerclage application may be performed percutaneously with minor impairment of periosteal perfusion and good results.\textsuperscript{21}

As an alternative to cerclage fixation, the development of polyaxial screws and precontoured periarticular (periartrophic) plates might be an advantage in improving PPF fixation.\textsuperscript{22-24}

In order to preserve the perfusion of bone and surrounding tissue in fractures, ‘minimally invasive’ strategies are recommended by some authors.\textsuperscript{12-14,23}

To date, reduced and ‘minimally invasive’ surgical (MIS) techniques have been introduced based on better anatomical understanding as well as better periopeative and intra-operative visualisation technology. Therefore, for various musculoskeletal trauma indications, the periopeative risks and the local soft-tissue damage have been reduced even for the stabilisation of ‘central injuries’ such as the shoulder and the spine.\textsuperscript{25-27} Nevertheless, MIS strategies in PPF fixation remain challenging with respect to reduction and fixation techniques.

Along with a growing number of pertrochanteric fractures (in Germany approximately 100,000 per year), more and more peri-implant fractures (PIFs) at the level of a proximal femur nail are seen.\textsuperscript{2} As the problem of fixation can be compared to the situation of an intramedullary prosthetic implant, these cases were included in this study. The primary aim of the presented study is the description of our experience in combining a precontoured periarticular polyaxial plating system with a standardised less invasive approach for the treatment of PPFs and PIFs. As there is a high inhomogeneity in patients treated for this fracture type with respect to the local (e.g., type of prosthesis) and the general (e.g., mobility of the patient) states, we tried to structure the paper based on the following sub-items:

- S1: impact of two standardised procedures for less invasive PPF/PIF fixation,
- S2: application of polyaxial locking screws in PPF/PIF fixation,
- S3: impact of a new PPF plate and
- S4: radiological healing, outcome and mobility after 12 months.

The study was approved by the ethical committee of the Hospital of the University of Giessen and Marburg; location Marburg (Nr. 110/10).

**Patients and methods**

From February 2008 to February 2011, a consecutive cohort of 41 patients with 41 PPFs or peri-implant femoral fractures was operated on and prospectively documented at the authors’ institution. Informed consent was obtained from all the patients or their relatives.

Patients were excluded from the study in cases of:

- loose hip or knee prosthesis (Vancouver type B2 and B3 or Rorabeck type 3),
- pathological fracture caused by local malignant destruction of the bone and
- PIFs with proximal failure of fixation.

In all cases, the stability of the prosthesis was evaluated by preoperative X-ray and clinical evaluation (e.g., history of pain before the fracture). The classification of the PPFs was based on the Vancouver classification\textsuperscript{17} in the proximal femur and on the Rorabeck classification\textsuperscript{18} in the distal femur. In order to plan the surgical approach, the Orthopaedic Trauma Association (OTA) classification of femur fractures (types 32 and 33) was applied.

All early and late complications were documented based on a standardised evaluation.

**Surgical techniques (S1)**

Two operative techniques are defined: (a) the ‘mini-open’ technique and (b) the ‘minimally invasive’ technique.

The ‘mini-open’ approach is indicated in two-part long spiral fractures (Fig. 1(a) and (b)) classified as OTA type 32 or 33-A1 fractures.

The ‘minimally invasive’ approach was applied to all other fracture types, mainly multifragmented fractures or short oblique fractures. When the surgeon is not able to reduce such a fracture by

---

**Fig. 1.** a.p. (a) and lateral (b) view of a Rorabeck type 2 and OTA 33-A1 fracture of a hinged TKA in a 76 year old female patient. Because of the stem and the box there is only limited bone stock in the distal femur (b).
a 'minimally invasive' approach, a 'mini-open' approach could be performed.

(a) ‘Mini-open’ technique: Before the NCB plate was inserted, an open reduction and temporary fracture fixation was performed. For this step, an incision at the level of the fracture was made that was sufficiently long to expose the fracture region. The two fragments were reduced with the help of forceps until anatomical alignment of axis and rotation was achieved. The reduction forceps was then replaced by one or two cerclages (Fig. 2(a)).

After this step, the plate was inserted and temporarily fixed with K-wires proximally and distally. Before the screws were set, a lateral view to control the plate position was performed by use of the intensifier (Fig. 2(b) and (c)).

The screws in the diaphyseal region were inserted percutaneously. The femur was not exposed in the diaphyseal area (Fig. 3(a) and (b)). All screws were locked.

(b) ‘Minimally invasive’ technique: The concept of this technique is a totally closed reduction (Fig. 4(a) and (b)). This was achieved by either ligamentotaxis and/or the application of the plate as a template. Therefore, correct alignment by axial traction was maintained throughout the whole procedure. Traction was exerted by the assistant surgeon. In cases with mid-shaft fractures, a traction table was used.

After closed reduction, the plate was inserted on the level of the prosthesis after a short 3–4 cm incision. The broad part of the plate...
(the metaphyseal end) was placed on the fragment where the prosthesis was in place (Fig. 5).

After this step, the plate was temporarily fixed with K-wires proximally and distally (Fig. 6(a) and (b)). Before the screws were set, a lateral view to control the plate position was performed with the intensifier.

By setting the shaft screws, the plate was used as a reduction tool (Fig. 6(c) and (d)). The screws were locked with a cap when the plate was running parallel to the diaphysis.

Before the screws were placed in the metaphyseal area, a control of the axis was performed, using in our institution, the ‘cable technique’.28 With this method, the straightened cable of the electric coagulation device simulates the mechanical axis. Correct reduction was achieved when the intensifier showed that the cable was running through the centres of the hip, knee and ankle. Thereafter, the screws were set in the metaphyseal region (Fig. 7(a) and (b)).

**Locking mechanism and implant (S2 and S3)**

All fractures were treated with an anatomical polyaxial locking plating system, NCB® (Non-Contact Bridging Plate, Zimmer Inc., Winterthur, Switzerland). The implant offers the possibility of a polyaxial locking screw fixation up to 15° in any direction to the plate level (full range, 30°). This design allows a reduction of bony fragments in the direction of the plate by the screws before they are locked. Intramedullary implants can be ‘bypassed’ by the screw. The angular stability is achieved by fixing the head of the screw with an additional cap threaded into the plate.

The plate is preformed for the left and right sides. The NCB–DF® (Non-Contact Bridging Plate–Distal Femur) is made from

---

**Fig. 5.** Intraoperative picture of a minimally invasive insertion of a periprosthetic plate (NCB PP).

**Fig. 6.** Intraoperative X-ray pictures demonstrating the MI technique of closed reduction with temporary proximal and distal plate fixation (a and b) and reduction of the fragments by the screws through the plate (c and d).

**Fig. 7.** Follow-up X-ray picture at 6 months after surgery. 8 proximal locking screws were placed around the prosthesis.
titanium (cp Ti) and is available in three different lengths: 167 mm (five holes in the diaphyseal part), 246 mm (nine holes) and 324 mm (13 holes).

From September 2010 on, the modified periprosthetic plate (NCB–PP®) with the same locking mechanism but a broader metaphyseal area (Fig. 2(c)) and configurations for the proximal femur was used. This plate is available with 12, 15 and 18 diaphyseal holes. Before the introduction of the NCB–PP®, a contralateral NCB–DF® was applied in an antegrade insertion technique in cases with a Vancouver B1 fracture.

It was the goal to apply in both the diaphyseal and the metaphyseal areas of the femur at least four locked screws with eight cortices. If a screw had to bypass a thick (uncemented) prosthesis, it happened that it fixed only one cortex. Under these circumstances, the number of screws was augmented or additional cerclages were set around both the plate and the bone (Figs. 3(a) and 7(a)).

Complications and follow-up (54)

All patients were mobilised out of bed during the first postoperative days. Full weight bearing, though, was not allowed during the first 6 weeks. The first clinical and radiological follow-ups were performed after 6 weeks, before the start of full weight bearing. Because it was difficult to motivate geriatric patients to come to a follow-up, only two additional dates (at 6 and 12 months after the operation) were planned.

If the patient was not willing or able to present at the follow-up at 12 months, a structured telephone interview with the patient, a close relative or the patient’s physician was performed.

The Glasgow Outcome Scale (GOS®) was used to determine the general outcome and to compare the gross status of pre- and postoperative activity.

Statistical analysis

For statistical analysis, both Microsoft Excel 2007 and Statistical Package for the Social Sciences (SPSS) Statistics 17.0 were used. Groups without normal distribution were evaluated by performing the Mann–Whitney U test. A p-level of ≤0.05 was set as being statistically significant.

Results

The cohort of 41 patients comprised 33 women and eight men. Their age averaged 79.8 ± 11 years; 37 patients were 70 or more years old. According to the advanced age, 39 (95%) patients presented with 1–6 (mean 2.4) important pre-existing medical conditions (e.g., diabetes and hypertension). The American Society of Anaesthesiologists (ASA) classification with a mean score of 2.8 ± 0.6 revealed that most of the patients presented with a high perioperative risk for complications.

In 23 cases the right side and in 18 cases the left side was affected.

Mechanism of injury

In 33 patients, the fracture was caused by a fall from low height (during walking or getting out of bed). In six cases, no adequate mechanism of injury could be reported. In two patients, the fracture was detected in the postoperative X-ray 4 days after an operative procedure (1 × proximal femur nail; 1 × total hip arthroplasty, THA).

Fracture types and implants

The PPF group comprised 17 isolated periprosthetic THA fractures (10 × Vancouver type B1 and 7 × type C), 10 isolated periprosthetic total knee arthroplasty (TKA) fractures (Rorabeck type 2 only) and three interprosthetic fractures (Vancouver type C and Rorabeck type 2) (Table 1). Among the periprosthetic THA fractures, there were eight uncremented and 12 cemented prostheses, and in the TKA group three patients had an intramedullary stem fixation. The prostheses were implanted before the fracture at a mean of 72.7 months (1–205 months).

In the PIF group (n = 11), there were 10 proximal intramedul- lary pertrochanteric femur nails and one nail for knee arthrodesis (Table 1; Fig. 8(a) and (b)).

Surgical techniques (51)

The time interval between trauma and surgery was 25.8 ± 20 h on average. The earliest operation was performed 3 h after the injury; the longest time interval was 12 days.

Depending on the fracture type, in 22 cases a ‘mini-open’ (MO group) and in 19 cases a ‘minimally invasive’ (MI group) procedure was performed (Table 2). There were no statistically significant differences between the two groups. Nevertheless, a tendency towards a longer operation time (cut to closure) in the MO group (116.7 vs. 97.1 min) was documented. The duration of intraoperative use of X-ray was not significantly different (3.3 vs. 2.8 min). No significant differences were found with respect to the need for transfusion during the operation and the postoperative 24 h (MO 59% vs. MI 42%), or the length of the postoperative stay in the ICU (MO 52 vs. MI 73 h) (Table 2).

Fixation techniques (52 and 53)

In 34 (83%) cases, there was an intramedullary implant in the distal or proximal femur that interfered with the screw placement. In addition, seven patients had resurfacing TKA without an intramedullary fixation.

The fixation of the plate to the bone was achieved by 5.4 screws on the prosthetic/implant side and by 5.7 screws on the diaphyseal side. If an intramedullary stem/implant had to be bypassed, an average of 5.3 screws could be set. In 10 (24%) cases, one additional
cerclage was used to fix the plate to the fragment (Fig. 3(a) and (b)). In all but one case, these cerclages were used when a ‘mini-open’ technique was applied.

In 31 cases the NCB–DF\textsuperscript{HI} and in 10 cases the NCB–PP\textsuperscript{HI} plate was applied, respectively. There was a small difference between the types of plates with respect to the amount of peristem/peri-implant screws (NCB–DF\textsuperscript{HI} 4.8 vs. NCB–PP\textsuperscript{HI} 6.3).

Before the introduction of the NCB–PP\textsuperscript{HI} plate, in five cases a reverse contralateral NCB–DF\textsuperscript{HI} was applied to fix a PP–THA fracture.

**Postoperative course (S4)**

The stay in hospital averaged 16.7 ± 8 days. Only one patient had to be revised during the first stay in hospital (see procedure-related complications). Nevertheless, the rate of general postoperative complications was high; 24 (59%) patients developed 1–3 (mean 1.2) important postoperative complications (e.g., urinary tract infection), but there was no fatality in the whole group. After treatment in our department, 21 patients were referred to another hospital for geriatric rehabilitation while 20 patients returned to their private homes or to nursing homes for ambulant rehabilitation.

**Procedure-related complications (S4)**

The mortality rate after 12 months was high at 22% (n = 9). The patients who died were older (mean age 87 vs. 78 years) and in worse medical condition (mean ASA score 3.2 vs. 2.7) than the survivors. No death was caused by any implant-related procedure. All deaths occurred within the first 6 months after surgery (average

### Table 2

Operative and postoperative data comparing the mini-open (MO) and the minimally invasive (MI) procedure.

<table>
<thead>
<tr>
<th>Surgical technique</th>
<th>Age\textsuperscript{a}</th>
<th>OR time\textsuperscript{a}</th>
<th>Intraoperative X-ray time\textsuperscript{a}</th>
<th>Perioperative (24 h)\textsuperscript{b} PRBC</th>
<th>ICU-stay hours\textsuperscript{a}</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO</td>
<td>80.1 ± 8 years</td>
<td>116.7 ± 39 min</td>
<td>3.1 ± 1 min</td>
<td>2.4 ± 2 PRBC</td>
<td>52.2 ± 67 h</td>
</tr>
<tr>
<td>n = 22</td>
<td></td>
<td></td>
<td></td>
<td>(n = 13; 59% patients)</td>
<td>(n = 17; 77% patients)</td>
</tr>
<tr>
<td>MI</td>
<td>79.5 ± 14 years</td>
<td>97.1 ± 39 min</td>
<td>2.4 ± 2 min</td>
<td>3.1 ± 1 PRBC</td>
<td>73.0 ± 58 h</td>
</tr>
<tr>
<td>n = 19</td>
<td></td>
<td></td>
<td></td>
<td>(n = 8; 42% patients)</td>
<td>(n = 12; 63% patients)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Mean and standard deviation.

### Table 3

Complications within 12 months after the surgery.

<table>
<thead>
<tr>
<th>Surgical technique</th>
<th>Minor complication\textsuperscript{a}</th>
<th>Major complication\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO-group</td>
<td>n = 3 (7%)</td>
<td>Fracture of the plate: n = 2</td>
</tr>
<tr>
<td>n = 22</td>
<td>Temporary lesion of the femoral nerve: n = 1</td>
<td>Malrotation (20%): n = 1</td>
</tr>
<tr>
<td>MI-group</td>
<td>n = 19</td>
<td>Seroma: n = 1</td>
</tr>
<tr>
<td></td>
<td>15% malrotation: n = 1</td>
<td>Lateral ligamentous instability in TKA: n = 1</td>
</tr>
<tr>
<td></td>
<td>15% valgus deformity: n = 1</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} No surgical management.

\textsuperscript{b} Surgical management.
3.2 months). Except for one 88-year-old woman, all surviving patients consented to share the information about their actual state for the study follow-up.

During the follow-up period of 12 months, three (7%) minor (no surgical treatment) and five (12%) major complications (surgical management) were detected (Table 3). Among the three complications that were treated non-operatively, one patient postoperatively showed a temporary lesion of the femoral nerve, but the weakness of the quadriceps muscles disappeared during the 2 postoperative months. In an 86- and a 92-year-old patient, both already bound to wheelchairs before the operation, a postoperative internal rotation of 15° in one and a 15° valgus deformation in the other was documented clinically and radiologically (CT scan). Because of the patients’ low degree of mobility, an operative correction was not performed.

In five (12%) cases, a surgical revision was required (Table 3). In one patient, after the MO technique, a seroma was evacuated during the first stay in hospital. The wound and the fracture later healed uneventfully.

The further four revisions were performed within 6 months. Two patients after the MO procedure with a cerclage for fracture fixation suffered both fracture nonunion and plate breakage.

The first patient had a multiply fragmented fracture (Rorabeck 2; OTA 33-A3; Fig. 9), whereas the second had a short oblique Vancouver B1, OTA 32-A2 fracture. For revision, the plate was exchanged for a nail, and a prosthesis with a long stem was implanted, respectively.

In a third patient, the knee prosthesis had to be exchanged due to lateral ligamentous instability after 8 months. In a fourth patient, a fracture around a hinged knee prosthesis was fixed in 20° internal rotation. In this heavy patient (120 kg bodyweight, BW) with an OTA 33-A3 fracture, an MO procedure was performed because of intra-operative difficulties in closed reduction. The malrotation was not detected intra-operatively. The 79-year-old patient had already been mobilised with crutches prior to the fracture. In this case, only a soft-tissue reconstruction (lateral release and a medial patellofemoral ligament reconstruction) to centralise the course of the patella was performed (Table 3).

There was no case of infection in the study group.

**Follow-up (S4)**

Although all patients or relatives agreed to present at the follow-up examinations, not all could be seen at the 12-month follow-up. Nevertheless, from the surviving 32 patients all except one patient could be evaluated clinically or by telephone interview (follow-up rate of 97%). It has to be considered that the level of mobility of many patients was already low before the fall (Table 4). Therefore, at 12 months only 20 of 31 patients could come to the hospital. The other 11 patients were not able or willing to come mainly because of limited mobility. In this group, two patients were bedridden, five were bound to a wheelchair and four were walking with a frame prior to the accident. Of these patients, only two had a decrease in mobility compared to the preoperative state.

Comparing the activity level of the surviving patients at the 12-month follow-up to the pre-accident status, 14 (45%) exhibited a decrease in mobility. The GOS score showed an already elevated impairment of the general status of health before the trauma. Nevertheless, 68% regained their pre-existing health condition after 12 months.

**Radiological results (S4)**

At the 6-month follow-up, in 31 patients an X-ray of the operated femur could be obtained (of the other patients, nine had

---

**Table 4**

Preoperative and postoperative mobility and GOS-Score.

<table>
<thead>
<tr>
<th></th>
<th>Dead/lost to follow-up</th>
<th>Mobility (all/survivors 12 months)</th>
<th>GOS (all/survivors 12 months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before trauma</td>
<td></td>
<td>Free: n = 8/8</td>
<td>5: n = 7/7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Walking stick: n = 9/9</td>
<td>4: n = 21/16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frame: n = 16/11</td>
<td>3: n = 13/8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wheelchair: n = 6/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bed: n = 2/1</td>
<td></td>
</tr>
<tr>
<td>At 12 months*</td>
<td>Dead: n = 9 (22%)</td>
<td>Free: n = 6</td>
<td>5: n = 4</td>
</tr>
<tr>
<td></td>
<td>Lost: n = 1 (25%)</td>
<td>Walking stick: n = 6</td>
<td>4: n = 17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frame: n = 11</td>
<td>3: n = 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wheelchair: n = 4</td>
<td>2: n = 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bed: n = 4</td>
<td></td>
</tr>
</tbody>
</table>

* In these groups only the survivors at the 12 month follow-up were compared.
died and one was lost for follow-up). In two patients, there was a
breakage of the plate (around 6 months after surgery) due to failed
fracture healing. In all the other patients, the fractures showed
good and reliable callus formation in the antero-posterior and the
lateral view. At that time, the uneventful healing rate was 94%.

After 12 months, 20 patients came to the follow-up. In all these
patients, the fracture had united. In the telephone interview of the
other 11 patients (or relatives), questions about pain in the
operated leg and the fracture region and about new deformities
(since the 6-month follow-up) were raised. In all cases, the
answers did not show any signs of failed fracture healing.

Discussion

The aim of the presented prospective study was to evaluate the
effect of PPF or PIF treatment with a polyaxial locking plate
implanted in a standardised less invasive technique. There are two
major limitations of this study:

1. different types of PPFs and PIFs of the femur were included and
2. two different types of less invasive reduction techniques were
   applied for different types of fractures.

Despite the shortcomings outlined above, the study offers an
array of relevant information for the treatment of these
complicated fractures. The conception of the NCB\textsuperscript{30}
polyaxial locking system is a relatively new strategy that has been described
to date in only a few publications\textsuperscript{22–24} Furthermore, a standard-
dised strategy for less invasive fixation related to fracture type has
not been published until now.

Because of small cohort numbers, different types of fractures,
different types of prosthesis, different types of fixation and the
general lack of controlled studies, an optimal treatment for PPFs
has not been described until now. The recent literature on the
treatment of PPFs with locking plates reports 7–41% local
complications and 0–29% revisions\textsuperscript{9–14,22}

In our analysis of less invasive polyaxial locking fixation, a
relatively low rate of 7% minor complications and 12% surgical
revisions was found. Nonunion with implant failure was seen in
only two cases (5%). Furthermore, in the group of PIFs, no
complications were seen.

In this context, the results of this study can give additional
information on new options in the treatment of these complicated
fractures. The following discussion is based on the four main
questions of this study.

\textit{S1: Impact of two standardised procedures on less invasive PPF/PIF
fixation}

In order to preserve the blood supply of the bone and to
diminish local soft-tissue complications, ‘minimally invasive’
strategies are recommended by some authors even for PPFs.\textsuperscript{11,13,14}

Other authors still recommend the open approach.\textsuperscript{9,10,12,22,30,31}

Although the revision rates in the papers describing ‘minimally invasive’
techniques (0–12.5%) seem to be lower than in studies on
open approaches (7–29% revisions), a direct comparison cannot be
performed because of the varying fracture types, strategies and
implants.

In this study, we prospectively defined two less invasive
strategies for reduction and fixation (‘mini-open’ and ‘minimally
invasive’). The idea of developing a ‘mini-open’ technique was
based on the fact that adequate restoration of axis and rotation in
2-part (OTA-A1) fractures can be best achieved by direct
manipulation and compression of the fragments. We estimated
that local bone perfusion after direct manipulation in fractures
with two fragments that have a long surface of contact might not
be impaired too much. While this technique showed favourable
results when applied in A1 fractures, we found important
complications such as plate fractures due to failed biological
healing when this technique was used for 32-A2 or 33-A3
fractures (Fig. 9). Although MO is a viable option in long spiral
fractures, this emphasises the difficulty of finding the adequate
operative strategy in the presenting surgical indication. To our
experience, the length of the fracture area in an A1 fracture should
not be shorter than approximately 10 cm (Figs. 2(a) and 8(a)) to
allow the ‘safe’ placement of a cerclage. In unclear situations, for
example, suspicion of more than two fragments, or very
osteoporotic bone with the risk of an additional iatrogenic
fracture or of rather short spiral fragments, we recommend
performing the MI procedure.

On the other hand, in the MI group, only one surgical revision
was necessary because of the ligamentous instability of a
resurfacing TKA after 8 months. At that date, the fracture was
healed and a hinged prosthesis could be implanted. It is unclear
whether this complication was related to the procedure.

In two other cases, complications such as malrotation and
malreduction were documented. These patients were not revised
because of their low levels of mobility prior to the fall. In these
cases, just the fracture was fixed in order to facilitate painless
postoperative mobilisation. Although restoration of axis and
rotation is the goal of surgical fracture treatment, it sometimes
may be difficult to achieve this in closed reduction. Nevertheless, it
has to be taken into account that a high percentage of these
patients are bound to wheelchairs or frames, and mild deviations
in axis and rotation can be tolerated if fracture healing is achieved.

Comparing the two techniques with respect to OR time, intra-
operative use of intensifier, packed red blood cell (PRBC)
administration and need for ICU treatment, we did not find
statistically significant differences. Nevertheless, there is a
tendency to favour the ‘minimally invasive’ technique, which
suggests that the MI approach offers higher perioperative safety
than the other approach.

As additional advantages of the less invasive technique, it has to be
mentioned (as observed by other authors: Refs. 11, 13, 14) that
no additional bone graft was necessary and no infection was seen
in our study.

\textit{S2: Application of polyaxial locking screws in PPF/PIF fixation}

For fixation of PPFs, different techniques are described.

According to the literature, PPFs around a THA or a TKA are better
fixed by locking screws than by conventional screws.\textsuperscript{8} As an
alternative to resurfacing TKA, an intramedullary retrograde nail
can be applied if there is no closed box on the femoral component.

Until now, there have been no trials that compare nails and plates
in PPF around a TKA. There is a meta-analysis of 415 supracondylar
PPFs published by Herrera et al.\textsuperscript{9} that did not demonstrate any
clear difference in outcome between retrograde nailing and locking
plates.

Nevertheless, when a stable intramedullary stem/implant is in
place, a locking plate is the actual treatment of choice in a PPF.

However in monoaxial locking systems, the bicortical fixation of a
plate is difficult to achieve in areas with an intramedullary implant.

Monocortical screws can be placed as an alternative. Whereas, if
only (or mainly) monocortical unicortical locking screws are set, a
high risk of pullout and implant failure exists in osteopenic bone or
uncemented implants.\textsuperscript{9,12,13} Therefore, some authors recommend
additional cable or cerclage fixation in these circumstances.\textsuperscript{9,11,14}

The NCB\textsuperscript{30} system, with its 30° polyaxial locking mechanism,
allows the positioning of a locked bicortical screw around an
intramedullary implant. In our study, we were able to set a
minimum of 3 and a mean of 5.4 bicortical screws around a stem.
We combined this fixation technique in 24% of patients with an additional cerclage in order to achieve optimal stability when fewer than 4 screws could be set (Fig. 3). Based on this strategy, we did not see any case with loss of fixation in our study.

In order to provide stable fixation with a sufficient number of screws on each fracture side, preferably long plates with a length of more than 24 cm were used in 88% of patients. The less invasive technique enables use of these long plates with reduced soft-tissue damage. In our study, only one (2%) relevant complication in the soft tissue (seroma) was found.

As an additional advantage, the NCB\(^ {\text{TM}} \) mechanism of locking enables the use of every screw as a lag screw through the plate when it is appropriate. Thus, especially in less invasive surgery, reduction of the fragments to the plate can be performed. All screws can be locked once reduction is achieved (Fig. 6(c) and (d)). This might be a reason why breakage of screws was not observed in our study. Other authors did find screw breakage rates in up to 14% of cases,\(^ {31–33} \) especially when non-locking screws were applied in monoaxial locking systems (hybrid technique\(^ {11} \)) in order to perform reduction through the plate.

The rate of implant failure was very low (5%) in our study. There were only two late breakages of the plate after 6 months. In both cases, the analysis revealed an impaired biological healing at the fracture site after direct manipulation (‘mini-open’ technique; Fig. 9).

### S3: impact of a new PPF plate

In 10 cases, we applied the new periprosthetic NCB–PP\(^ {\text{TM}} \). The main difference in design in comparison to the distal femur NCB–DF\(^ {\text{TM}} \) is that the plate is broader in the metaphyseal region with more options for screw placement (Fig. 2(b) and (c)) and that there is a design for proximal fractures. To our knowledge, this is the only plate design for proximal periprosthetic femur fractures. Before the introduction of the NCB–PP\(^ {\text{TM}} \), in our hospital we successfully applied the contralateral NCB–DF\(^ {\text{TM}} \) in proximal fractures (around a THA) in five cases. This technique was already described by other authors for different locking plates (e.g., LISS system; Synthes\(^ {\text{TM}} \); Refs. 34, 35). Besides the fact that no ‘off-label’ use of the plate has to be performed in proximal fractures, an increase of screw placement around a stem/implant could be observed (NCB–DF\(^ {\text{TM}} \) 4.8 vs. NCB–PP\(^ {\text{TM}} \) 6.3).

### S4: outcome and mobility after 12 months

The literature offers mostly coherent information on the postoperative course of patients with PP fractures:\(^ {19–14,30,31,36} \)

- patients are of advanced age, mostly in their 70s and 80s, and have a high rate of age-dependent risk factors,
- preoperative mobility is already impaired up to 50%,
- early postoperative mortality is low and mostly not directly related to the procedures for fracture fixation (even in cases with local complications),
- fracture healing is delayed, but most authors describe a successful bony union after 4 or 6 months and
- due to the geriatric state of the patients, the 12-month mortality can be high (up to 33%) and is mostly not related to the procedure of fracture fixation.

Although we were not able to see all patients in hospital at the 12-month follow-up because of their limited mobility, we received sufficient information about their actual state at the time of follow-up. Our results on the post-hospital course do not show any strong difference from the actual literature.

It has to be mentioned, though, that in our series, there were eight patients who showed a high degree of immobility (six in wheelchair, two bedridden) prior to the fracture due to a poor general state of health (GOS of 3). To achieve optimal post-trauma care and mobilisation, all were treated operatively and quickly returned to their nursing homes. Although the first-year mortality was 63% (n = 5) in this subgroup, no patient developed any local complications with need for re-admission to the hospital.

Our data demonstrate the ability to stabilise PPFs by the application of polyaxial locking plates in a less invasive technique, even in very sick patients, with a relatively low complication rate.

### Conclusions

The typical patient with a PPF presents with very poor pre-existing health conditions and elevated surgical risk factors. The central strategic focus is an individually conditioned, safe and quick surgical procedure with a low rate of local complications. To help meet these demanding surgical and medical needs, the less invasive polyaxial locking plate fixation techniques are promising options.

If possible, direct manipulation of the fracture zone, as in the ‘minimally invasive’ technique, should be avoided. Only selected two-part spiral fractures (OTA type A1) with a long contact area allow for direct reduction and cerclage fixation in order to achieve optimal axis and rotation. There is an elevated risk of local complications when the ‘mini-open’ technique is applied to other fracture types.

The NCB\(^ {\text{TM}} \) system, with its 30° polyaxial locking mechanism, allows for the positioning of a mean of 5 locked bicortical screws around an intramedullary implant and enables the use of every screw as a lag screw through the plate when it is appropriate. In the less invasive technique, long plates can be applied with low rates of soft-tissue complication and implant failure. Accordingly, no failure of fixation was seen in any of the 41 study patients.

### Conflict of interest statement

The authors declare that they have no conflict of interest.

### References


