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ORIGINAL STUDY

Treatment of extracapsular hip fractures with the proximal femoral nail (PFN) : Long term results in 45 patients

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The authors have retrospectively studied the results achieved with the AO/ASIF PFN system in the treatment of unstable intertrochanteric fractures of the proximal femur.

Between June 1999 and February 2003, 51 patients with unstable intertrochanteric fractures of the proximal femur underwent intramedullary nailing with the PFN system. A total of 45 patients (28 women, 17 men, average age 72 years) with 46 unstable pertrochanteric fractures (21 31-A2, 25 31-A3,) were available for outcome analysis. Mean follow-up period was 20 months (range, 12 to 30). The Salvati and Wilson scale of hip function was used at the last follow-up clinical assessment. Intraoperative difficulties in the insertion of the nail or screws, fracture consolidation, technical or mechanical complications and delayed union, nonunion and avascular necrosis were registered as well.

Solid union of the fracture was achieved in all patients except one who was revised to total hip arthroplasty because of avascular necrosis of the femoral head. Technical and mechanical complications were noted in 41.3% of the patients during the operation and in 30.4% at the follow-up period (2 cut-outs of the neck screw, 5 "Z effects" of the antirotational hip pin leading to femoral head protrusion in four of these cases, 1 case with reverse "Z-effect" and 2 implant failures, both revised to a long PFN implant). The overall rate of re-operation was 28.8%. The Salvati and Wilson score was > 25 in 27 (60%) of the patients.

The PFN modifications might be responsible for the positive results in this study. Technical or mechanical complications seem to be related with the type of fracture, the operative technique and the time of weight bearing rather than the PFN system itself.

INTRODUCTION

Intertrochanteric femoral fractures are common in elderly patients. The treatment of unstable fractures, type 31-A2, 31-A3 according to the AO classification (*17*), requires a surgeon with considerable experience in these injuries. Implant failure and other complications are relatively common, particularly in non-compliant patients.

The most widely used extramedullary implant – the dynamic hip screw (DHS) – seems to have a biomechanical disadvantage when compared with intramedullary devices because the load bearing in

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the proximal femur is predominantly shared by the calcar. Intramedullary devices such as the Gamma nail (GN) and proximal femoral nail (PFN), are more stable under loading with a shorter lever arm, so the distance between the hip joint and the nail is reduced compared with that for a plate, thus diminishing the deforming forces across the implant (*14*). For stable fractures the biomechanical disadvantage of the DHS does not appear to result in a significant difference in failure rate, and the DHS is therefore preferred because it is familiar and relatively cheap. However, for unstable trochanteric and subtrochanteric fractures the failure rate for a DHS is reported to be as high as 21% (*29*). Comparative studies between DHS and GN have shown a higher incidence of complications in the GN group, in particular fracture of the femur below the tip of the implant, collapse of the fracture area and cutting out of the femoral neck screw (*6, 7*).

The proximal femoral nail (PFN) was designed by the AO/ASIF group to overcome the above-mentioned limitations of the GN. We report our experience in the treatment of fractures of the trochanteric region of the femur using the PFN system and we discuss the commonest technical complications, mechanical failures and intraoperative difficulties during the application of this implant. A comprehensive review of the literature regarding the use of the PFN system is also presented.

PATIENTS AND METHODS

We conducted a retrospective study to evaluate the AO/ASIF PFN system for the treatment of unstable (AO 31A2, 31A3) trochanteric femoral fractures in a University Level 1 trauma center. Our unit is quite familiar with the use of the GN, which remains the implant of choice for the treatment of extracapsular hip fractures. The study concerns 51 patients with a trochanteric fracture of the proximal femur who underwent PFN implantation as an alternative treatment option. In fact, the PFN was tested for a short period but its use was restricted due to its high rate of technical or mechanical failures and reoperation. Four patients who died from reasons not obviously related to the surgery and two who did not attend the last follow-up visit were excluded from the study. A total of 45 patients with 46 fractures (1 bilateral) were available for the outcome analysis. There were 17 males and 28 females, with an average age of 72 years (range : 29 to 93 years). Enrollment in our study was from June 1999 through February 2003, with an average follow-up period for surviving patients of 20 months (range : 12 to 30 months).

A case documentation form was used for intra-operative data including age, gender, mechanism of injury, type of fracture according to AO classification and the American Society of Anesthesiologists physical status classification (ASA grade). A total of three consultants and six residents made up the main operating team. A fracture table and an image intensifier were used in all cases. All patients received one dose of 2nd generation cephalosporin intraoperatively and 2 doses postoperatively, and subcutaneous low molecular weight heparin starting on the day of admission until the 4th postoperative week. We followed the operative technique as described in the operative manual.

Patients were followed-up at 6-week intervals for the first 6 months and at 1-year intervals thereafter. The Salvati and Wilson score (*6*) of hip function was used at the last clinical assessment. Cut-out of the neck screw, Z-effect or reverse Z-effect of the hip pin, wrong length or inability to apply the hip pin or the distal screws were scored as technical failures, whereas breakage of the implant or fracture at the tip of the nail were defined as mechanical failures. Delayed union or nonunion and avascular necrosis of the femoral head were registered as well.

RESULTS

Forty-five patients with 46 fractures were available for the outcome analysis. Twelve patients (26%) had been using crutches prior to their admission. A fall at home was the commonest mode of injury (67% of the patients). Twelve patients had a road traffic accident ; 8 had associated injuries and one patient had bilateral intertrochanteric fractures. According to the AO/ASIF classification, there were 21 31-A2 and 25 31-A3 fractures. Sixty-five percent of the patients had significant comorbidity, mainly cardiopulmonary inefficiency, diabetes mellitus and a history of stroke or deep vein thrombosis, with 53% of them scored as ASA 3 or 4.

The average time from injury to surgery was 3 days (range : 0 to 7 days). Fifteen patients were operated under general and 30 under spinal anaesthesia. Eleven procedures were performed by experienced residents and 35 procedures by consultant surgeons. The mean operative time (skin to skin) was 68 minutes (range : 55 to 240 min). An apparent learning curve could not be detected, however 29 (63%) of the procedures were reported to be easy or at least "usual". The estimated intraoperative blood loss was 0.5 to 1.8 units.

In all patients 17-mm reaming of the proximal femur was done to accommodate the proximal part of the nail according to the suggested technique. Distal locking was used in all the patients, i.e. dynamic in 16 (through the oval shaped hole) and static in 30 fractures (using both distal holes). Difficulties at the insertion of the nail were experienced in 6 patients ; three patients required reaming of the femoral shaft to accommodate the distal part of the nail, and in another 3 patients an open reduction of the fracture was necessary since closed reduction was not feasible. Proximal locking was poor in 6 patients ; inappropriate length of the screws was noted in 3 of them and inability to insert the antirotational hip pin because of inadequate space in the femoral neck in the other 3 cases. In two cases, the antirotational hip pin was not inserted, as the fracture was considered quite stable according to the surgeon's intraoperative estimation. We encountered difficulties in distal locking in 5 patients due to misalignment of the targeting device ; for that reason we resorted to free-hand technique and in 2 of them the most distal screw was not inserted. There was one case of intraoperative undisplaced femoral fracture below the tip of the nail because of unduly hammering during insertion of the implant and one case with intraoperative extension of an existing fracture line in the trochanteric area. Both cases were managed conservatively with delay in full weight bearing for a period of 6 weeks.

During the immediate postoperative period, 15 patients suffered from systemic and 8 from local complications (table I). No cases of early fixation failure were recorded.

Immediate full-weight bearing was allowed in 35 (45%) patients and partial weight bearing in the remaining 10, depending on the type of fracture, the general condition of the patient and the intraoperative assessment of stability of the implant.

Table I. — Systemic and local complications

Complications	*No of patients*
Systemic (total = 15 (33%))	
Chest infection	1
Pulmonary embolism	2
Respiratory distress	2
Mental disturbances	3
Urinary tract infection	2
Urinary retention	3
Deep venous thrombosis	2
Local (total = 8 (17.7%))	
Haematoma	5
Superficial wound infection	2
Delayed wound healing	1

Forty-five patients with 46 fractures were available for the final follow-up analysis. All fractures but one that was revised to total hip arthroplasty because of avascular necrosis of the femoral head, had united at the time of final follow-up (fig 1). Dynamisation of two static nailings was performed in 2 patients due to delayed union, 16 and 18 weeks postoperatively. No cases of nonunion were noted. In two cases, i.e. a low subtrochanteric comminuted fracture and a subtrochanteric segmental fracture, the PFN nails broke at the level of the more proximal distal screw after a second fall, respectively 2 and 4 months postoperatively ; in both cases the implant was exchanged to a long PFN (fig 2). As previously mentioned, the antirotational hip pins had not been applied at the first operation in these particular cases.

The overall rate of late technical and mechanical complications was quite high (30.4%) (table II). Cutting-out of the proximal screws was seen in 2 cases, which were revised to a DHS and a GN respectively, and a Z-effect phenomenon was seen in 5 cases. Four of them led to protrusion of the hip pin through the femoral head, and were managed with implant removal (fig 3). The other case did not lead to protrusion as the hip pin was quite short. One case with reverse Z-effect was managed with removal of the antirotational hip pin but a secondary cut-out of the neck screw followed after a few weeks, and the hip was revised to total hip arthroplasty (fig 4).

Fig. 3. — Unstable A2 fracture with excellent outcome one year postoperatively

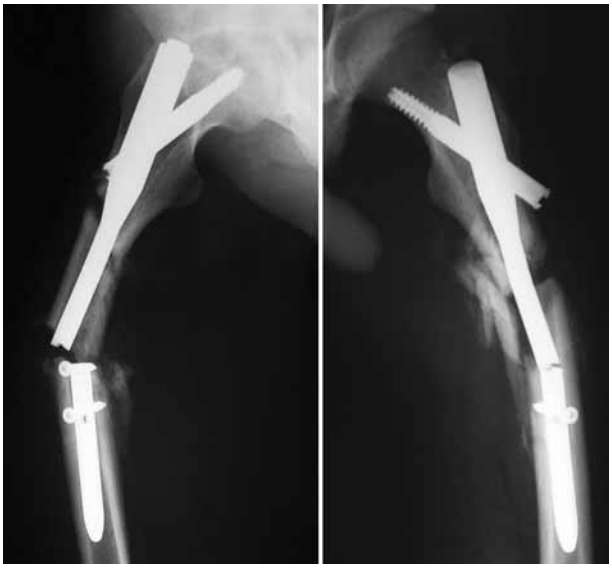

Fig. 2. — Two cases of implant breakage after a second fall at the level of the more proximal screw hole.

Persistent deep infection was not noted. Two patients were revised to total hip arthroplasty, two to exchange nailing with a long PFN implant and another two to the DHS and GN implants. Therefore together with the 5 patients in whom the implant was removed due to Z-effect or reverse Z-effect and the 2 patients in whom a dynamisation of the implant was performed, a total of 13/46 (28.8%) patients had to be re-operated.

At the final follow-up, 28 (62%) patients were walking with some sort of crutches, while the rest needed no aid (fig 5). The Salvati and Wilson score (maximum = 40) was > 25 in 27 (60%) patients (fig 6).

DISCUSSION

The need for internal fixation and early mobilisation of patients with trochanteric fractures of the femur is generally accepted, not only to reduce the morbidity/mortality rates associated with prolonged immobilisation, but also to improve the functional result through avoiding malunion and encouraging mobility (*27*).

The best treatment for these fractures remains controversial. DHS fixation is widely preferred but failure of fixation still occurs in up to 20% of

Table II. — Mechanical and technical complications related to the implant

Implant complications	*No of patients*
Technical failures	
– *Intraoperative*	
Open reduction of the fracture	3
Reaming of the shaft	3
Inappropriate length of proximal screws	3
Inability to apply the hip pin	3
Difficulties in distal locking	5
Fracture of the greater trochanter	1
Fracture below the tip of the nail	1
– *Late*	
Neck screw cut-out	2
Z-effect	5 (4 hip pin protrusions)
Reverse Z-effect	1 (leading to cut-out)
Malrotation/varus deformity	4
Mechanical failures	
Fracture below the tip of the nail	0
Breakage of the nail	2

Fig. 3. — A case of an unstable A2 fracture. Postoperative reduction was not anatomic, the hip pin was quite long and both proximal screws were at a higher level than the end cup of the nail. After 3 months the hip pin protruded into the acetabulum (Z-effect), although the fracture was finally united.

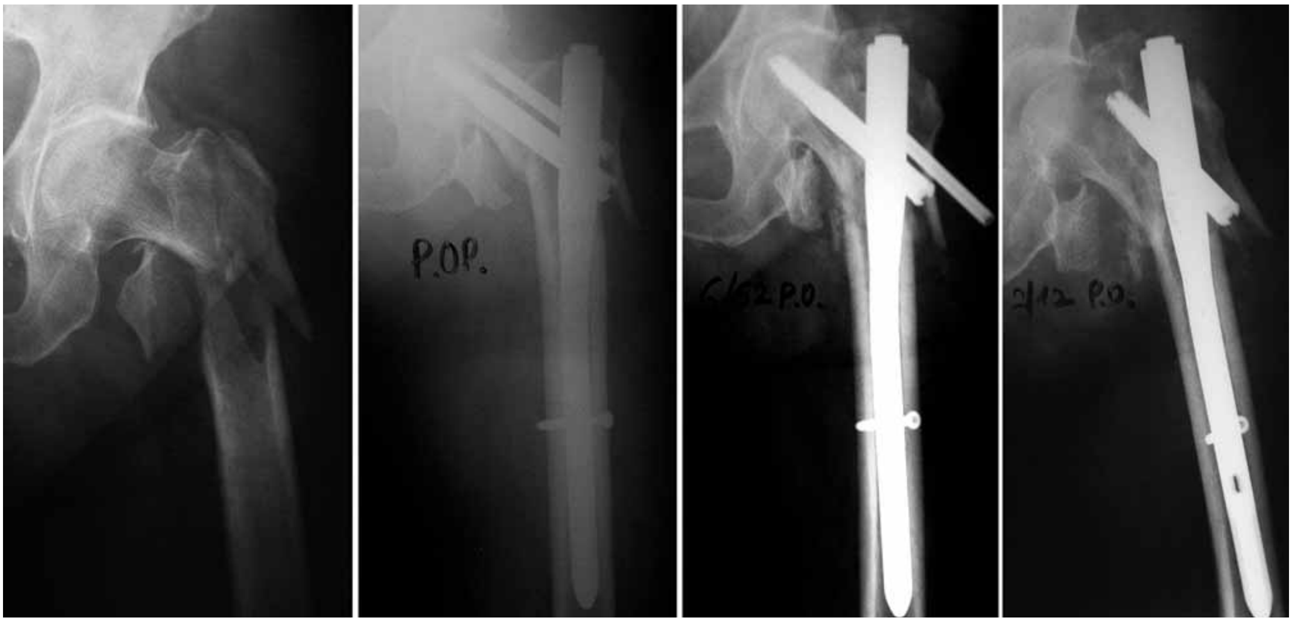

Fig. 4. — A case of reverse Z-effect. Although the postoperative reduction is quite acceptable, the hip pin was slipped back whereas the neck screw remained stable. After removal of the hip pin, secondary cut-out through the femoral head occurred.

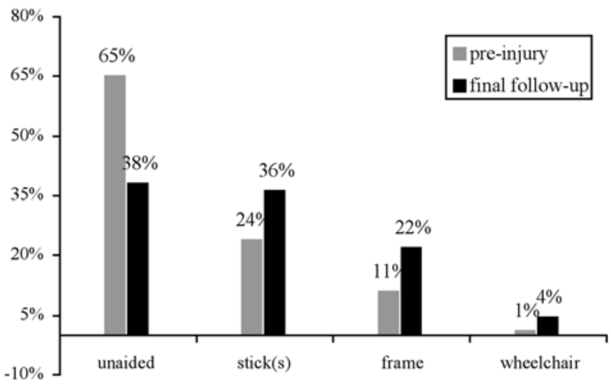

Fig. 5. — Walking ability of the patients before injury and at the final follow-up.

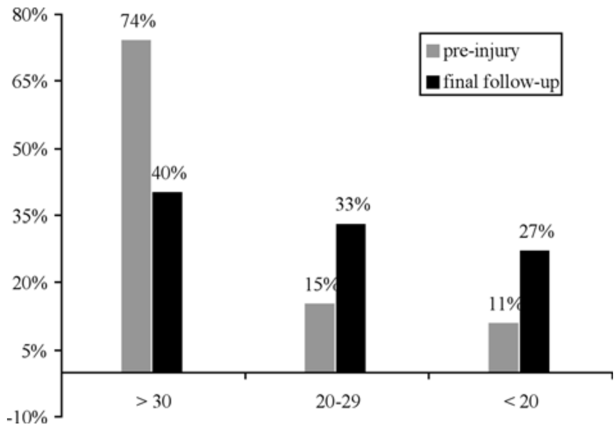

Fig. 6. — Clinical score according to the Salvati and Wilson hip function scoring system, preoperatively and at the final follow-up.

cases (*26, 29*) whereas in cases of low subtrochanteric fractures, DHS fixation usually prevents dynamisation at the fracture site. Intramedullary devices, such as GN, have some theoretical advantages over the DHS, as they do not depend on screw fixation of a plate to the lateral cortex, which can be a problem in very osteoporotic bone. In addition they have a shorter moment arm, because the load is transmitted to the femur along a more medial axis. The GN is more rigid than the DHS (*8*), has greater stability under cyclical loading (*10*) and greater stiffness under strain (*20*). On the other hand the GN has a significantly increased risk of fracture at the tip of nail, which had reached up to 18% in various studies, and other technical failures (8-15% of the cases) resulting in a high risk of reoperation (*1, 6, 7, 15*). Inadequate reaming and the use of excessive force during insertion have been implicated, but surgical technique may also be responsible, especially in cases of late femur fractures, due to abnormal strains imparted by the implant to the femur (*13, 19*). Parker and Pryor (*18*) carried out a meta-analysis of 10 studies comparing DHS and Gamma-nail, and did not find statistically significant differences in the incidence of proximal protrusion of the cephalic screw, whereas they reported a higher incidence of femoral fracture around the tip of the GN. The authors did not recommend using the GN in routine cases.

The PFN system, developed by AO/ASIF, has some major biomechanical innovations to overcome the previously mentioned limitations of the GN :

a) the addition of the 6.5 mm anti-rotation hip pin to reduce the incidence of implant cut-out and the rotation of the cervico-cephalic fragment,
b) the smaller diameter and fluting of the tip of the nail, specially designed to reduce stress forces below the implant and therefore the incidence of low-energy fracture at the tip,
c) the greater implant length, smaller valgus angle and setting of this angle at a higher level (11 cm from the proximal end), and
d) the more proximal positioning of the distal locking, to avoid abrupt changes in stiffness of the construct. In this respect, it should be borne in mind that the neck screw must be adjusted to the calcar, taking into account the need to place the antirotational hip pin.

There have already been several large studies analyzing the use of PFN, and four comparative studies (table V). Simmermacher *et al* (*18*) reported an overall technical failure rate of only 4.6%, in a series of 191 fractures (of which 170 were unstable) and no cases of mechanical complications such as fracture below the tip or bending/breakage of the implant. Domingo *et al* (*9*) prospectively evaluated 295 patients in whom the majority (59%) had an AO A2 intertrochanteric fracture and reported technical complications in 12% of the patients during the operation, 27% in the immediate postoperative period and late complications in 4%. Banan *et al* (*4*) reported a higher technical failure rate (8.7%) due to cut-out, 1 case of implant failure and 2 cases of fracture below the tip of the nail after a second fall, out of 60 patients with exclusively unstable trochanteric fractures. Al-Yassari *et al* (*2*) reported an 8% incidence of cut-out and one case of fracture around the tip of the nail after a second fall, in a total of 76 patients. Among the four cases of screw cut-out, there is one of protrusion of the antirotational hip pin (Z-effect ?).

Werner *et al* (*28*) were the first that introduced the term Z-effect, detected in 5 (7.1%) of 70 cases. The incidence of cut-out of the neck screw in this study was 8.6%. The Z-effect phenomenon is referred as a characteristic sliding of the proximal screws to opposite directions during the postoperative weight-bearing period ; normally a vertical force passing from the center of the femoral head tends to move the affected hip into varus as soon as the patient is mobilised. This leads to normal sliding of both proximal screws achieving the expected compression at the fracture site. In some cases this sliding occurs only to one of the proximal screws while the other remains in its initial position leading to penetration of the femoral head (fig 5). Analysing our 5 Z-effect cases, we noted that all these patients had unstable trochanteric fractures with comminution of the medial cortex. The postoperative reduction of the fracture was not anatomic and the proximal screws had been placed higher than the level of the end cup of the nail. A possible explanation for the Z-effect phenomenon is the impaction of the hip pin into the proximal hole of the nail while the neck screw is normally sliding back during the weight-bearing period. The proximal fragment and the femoral head are moved back normally, whereas the impacted hip pin protrudes through the head.

The reverse Z-effect described by Boldin *et al* (*5*) occurred with movement of the hip pin towards the lateral side, which required early removal. The mechanism is similar, but here the hip pin is sliding back, whereas the neck screw remains impacted to the hole of the nail. In their prospective study of 55 patients with unstable intertrochanteric or subtrochanteric fractures followed up for

Table III. — Technical and mechanical complications of the PFN system published in the literature

Author	Number patients	Type of fracture*	Technical failures	Cut-out	Implant failure	Fracture below the tip	Z-effect	Reverse Z-effect	Reoperation rate
Simmermacher (25)	191	A2 (67%)	4.7%	1	1	–	#	#	7%
Domingo (8)	295	A2 (59%)	12%	4	–	1	#	#	3%
Banan (4)	60	A2 (83%)	8.7%	4	1	2	#	#	6.5%
Al-yassari (2)	76	A2 (77%)	10.5%	4	–	1	#	#	7.1%
Werner (28)	70	A2 (54%)	25.7%	6	–	–	5	#	19%
Boldin (5)	55	A3 (62%)	18.7%	2	–	–	3	2	18%
Fogagnolo (11)	46	A2 (64%)	23.4%	5	2	1	#	(5$)	19.1%

* Most common according to AO classification.
# Not mentioned.
$ Described as intra-articular migration of the neck screws.

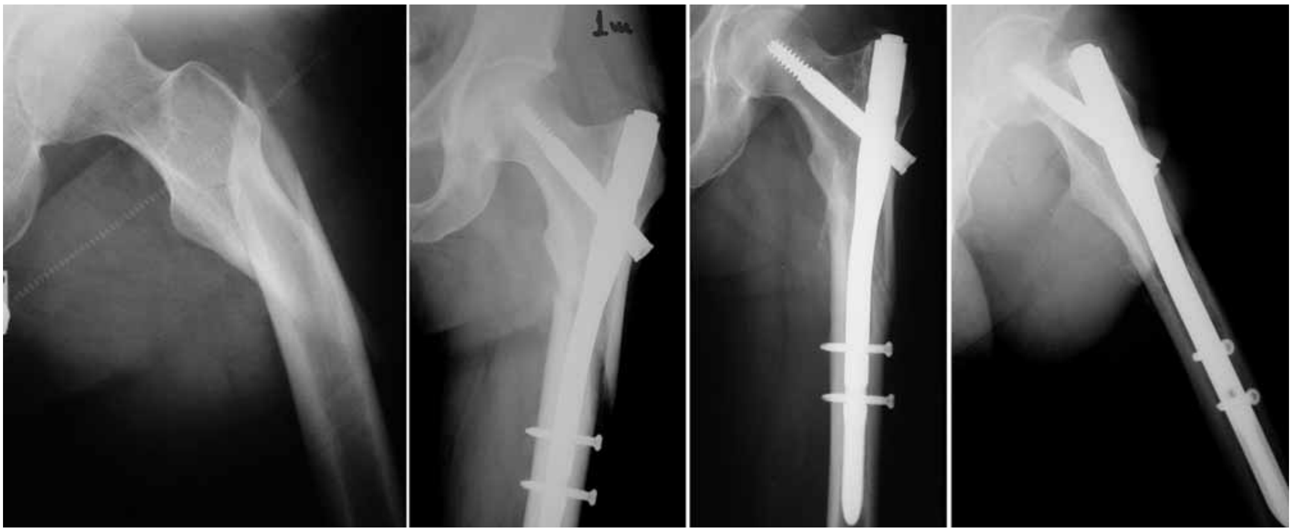

Fig. 7. — A case of A3 subtrochanteric fracture in which the antirotational hip pin was not applied because there was not enough space. The neck screw was applied first and in a more central position. The fracture was healed 4 months postoperatively.

15 months on average, they had 3 cases with Z effect and 2 with reverse Z-effect. The authors in an effort to prevent the Z-effect phenomenon suggest the use of a "ring" in the lateral side of the hip pin.

The most recent study evaluating the use of PFN is from Fogagnolo *et al* (*11*), who reported 46 patients with an average rate of intraoperative technical or mechanical complications of 23.4%. They also reported "lateral protrusion" of the screws in 21.2% of the patients, whereas 10.6% of them had "intra-articular migration" of the neck screws (reverse Z-effect ?). They also reported 2 implant failures and 1 fracture below the tip of the nail, whereas only 30% of their patients recovered the previous level of functional scores. The authors did not recommend the routine use of the PFN. Analysing the cases of "lateral or intra-articular protrusion" of the cephalic screws, they suggested as a possible explanation the fact that the screws were jammed or their sliding through the PFN did not proportionally follow the fracture subsidence or impaction and therefore the PFN implant acted almost as a fixed device.

Summarising all these phenomena of Z-effect, reverse Z-effect and lateral or intra-articular sliding of cephalic screws, it might be inferred that the PFN has a decreased sliding potential due to the absence of a barrel coupled to the proximal screws. The addition of such a barrel might permit the use of shorter screws and improve the sliding potential of the implant reducing the risk of those complications.

Except for the pre-mentioned isolated studies evaluating the PFN system itself, there have been four comparative studies between PFN and DHS, 95° dynamic condylar screw (DCS) and GN.

Saudan *et al* (*23*) compared in a population of 206 patients the DHS with the PFN in the treatment of low-energy trochanteric fractures (AO 31-A1 & A2). They found no advantages to the PFN, considering the patient outcome and the overall complications rate. The latter included 2 cases of hip screw cut-out and one migration of the hip pin into the acetabulum (Z-effect ?).

Sadowski *et al* (*21*) randomly compared the 95° fixed-angle Dynamic Condylar Screw with the PFN nail in a series of 39 patients (20 in the PFN group) with exclusively AO 31-A3 fractures. They did not report any major complications related with the implant, and they had one case of nonunion and only two minor reoperations. The authors suggested the use of PFN in unstable 31-A3 fractures.

Herera *et al* (*16*) in a comparative study of 250 pertrochanteric fractures treated with the simple GN or the PFN system (125 fractures in each group) reported a statistically significant difference in the incidence of neck screw cut-out (4%) and fracture below the nail (3.2%) in the GN group, whereas in the PFN group there was a higher incidence of secondary varus (7.2%) and collapse at the fracture site due to screw migration (8%).

Finally, Schipper *et al* (*24*), in a prospective multicenter clinical study, compared 211 patients with unstable trochanteric fractures treated with the PFN with 213 patients treated with the GN. They found more cases (7.6%) with “lateral protrusion” of the hip screws in the PFN group compared with the GN group (1.6%). Most local complications were related to suboptimal reduction of the fracture and/or positioning of the implant. Functional outcome and consolidation were similar for both implants.

Our series of 46 completely evaluated PFN implantations revealed a 77% primary postoperative full weight bearing possibility and showed fracture consolidation in 95.6% of the cases. Intraoperative difficulties were noted in 40.3% of the implantations and the overall rate of late technical and mechanical complications was 30.4%. Comparison of failures in this study to those in other series is not easy because an exact definition of failure is absent in most cases.

Distal locking difficulties in our series were seen in 5 (10.8%) cases. These can be avoided by firmly tightening the bolt joining the nail and the insertion handle at the time of distal locking. Loosening of the bolt can easily lead to malalignment of the aiming device. It is especially important to check the bolt if hammering is required for nail insertion. Inability to apply the antirotational hip pin was noted in 3 patients. In these particular cases, the neck screw had been applied first and in a position higher than the distal 1/3 of the neck thus leaving no room for the hip pin (fig 7).

The high stress concentration at the distal holes of the locking bolts of the GN-like implants, the suggested necessary over-reaming of the shaft that had been seen to weaken the entire shaft (*12*) and the frequent drilling for a proper distal interlocking because of misalignment of the aiming device (*3, 15*) are some of the reasons for the high incidence of fracture below the tip of the GN. The PFN modifications might be credited for the positive outcome in our study, as we did not note any fracture below the tip during the follow-up period. Intraoperatively there was only one case of incomplete fracture below the tip due to overreaming of the shaft for proper nail insertion.

We had two implant failures, both in low subtrochanteric fractures, with comminution of the shaft in the first case and a segmental fracture in the other. The nails broke at the level of the more proximal distal screw following a second fall. In these two cases, the standard PFN implants proved too short to maintain stability, and we should have used the long PFN implants from the beginning. However the fact that both nails were broken with minimal force at the level of the same screw is an evidence of a potential weak area of the implant at this level, due to its small diameter.

Two cut-outs through the femoral head (4.3%) occurred in this study. Both cases resulted from an inappropriate choice of the length of the proximal screws, which were quite short. The cut-out was noted in the early postoperative period as both patients had been allowed to walk with full weight bearing. In another case, secondary cut-out occurred after removal of the antirotational hip pin. Screw cut-out is related to malposition as in the DHS technique and can be prevented by proper positioning of the neck and anti-rotation screws (the anti-rotation screw should be shorter to allow sliding of the screws through the nail during weight bearing).

In accordance with similar reports, systemic and local complications and death rate in our study were not different. The number of reoperations due to technical or mechanical failures was quite high as was the incidence of intraoperative difficulties in PFN implantation. We also believe, as do other authors, that variables such as the duration of hospitalization, commencement of the sitting posture, early weight-bearing in unstable fractures are related to the pathology associated with advance age, general health status and type of fracture rather than to the surgical technique itself. At present we consider that the PFN is an acceptable minimally invasive implant for unstable proximal femoral fractures. Future modification of the implant to avoid the Z-effect phenomenon, careful surgical technique and selection of the patients should reduce the high complication rate.

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