Proximal Humeral Fractures and Intramedullary Nailing: Experience with a New Nail System

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Abstract

Objectives: The goal of this study was to evaluate fracture healing and alignment as well as functional outcome and complication risks after internal fixation with the intramedullary proximal humeral nail (PHN). This device shows promise for applications involving the reconstruction of the humeral shaft and head with minimal soft tissue stripping and for providing a locked, fixed-angle construct for secure fixation to permit controlled, early, and active rehabilitation.
Design: Prospective case-series.
Setting: Multicenter study in 11 trauma units.
Patients: One-hundred and fifty-one patients were treated for the same number of proximal humerus fractures.
Intervention: Open reduction and internal fixation with the intramedullary PHN.
Main Outcome Measurements: Occurrence of postoperative complications during and up to 1 year of follow-up. The patients were actively followed up for 1 year with radiological assessment to observe fracture healing, alignment, reduction, and necrosis and by functional outcome measurements, including Constant, Disabilities of the Arm, Shoulder and Hand (DASH), and Neer scores.
Results: A total of 113 patients (77% of 147 surviving patients) were available for the 1-year follow-up assessment, among whom 99% of all examined fractures had healed at this last time point. The range of motion (ROM) of the injured shoulder satisfactorily improved between all of the follow-up periods and by 1 year, 84–92% (ratio of injured to healthy contralateral shoulder) capacity had been achieved for all movements. The Constant score had significantly increased at the 3- and 6-month follow-ups, and by the final 1-year examination, this score attained up to 89% of the contralateral side. The mean baseline DASH was 5.9, with 62% of the total patient population having a zero DASH score. DASH scores higher than the pre-injury scores were only observed in patients > 90 years of age, with this score significantly increasing with a mean difference of five points at the 1-year follow-up. At this last examination time point, patients had also reached a "satisfactory" mean Neer score of 85. Intraoperative complications were few (i.e., only four cases were documented) and solely related to the surgical technique; these problems included perforation of the articular surface by the oblique bolt or incorrect positioning of an additional screw. Humeral head necrosis was not common, with only four cases

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observed. Implant/surgery complications occurred in 63% (30/48) of the patients and included 13 cases of "cut through" (secondary impaction of the humeral head), nine cases of perforation of the articular surface, and four cases of implant loosening. Only four deaths were reported, and all were considered to be purely related to the patient and not to their participation in this study.
Conclusion: Nailing of proximal humeral fractures with the PHN is possible, but indication is limited to mainly A- and B-type fractures. The results of this multicenter study with many participating surgeons show that the operative technique is demanding and that the majority of documented complications are related to a violation of published basic technical steps during the operative procedure.

Key Words
Intramedullary nailing of long bones · Shoulder and hand

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Introduction

Intramedullary nailing of humeral shaft fractures has been recognized as a serious alternative to plating. Both techniques, however, have been the subject of controversial discussions on functional outcome and non-union rates as well as the different complications associated with each technique. In terms of metaphyseal or even epiphyseal fractures, the standard humeral nails are inferior to plates due to the different fracture geometry, which presents quite a large problem to the nail insertion technique, but overall for the locking techniques.

There have been several technical developments for treating proximal metaphyseal humeral fractures, with the aim of providing appropriate interlocking in order to reach an anatomical reduction and sufficient stability for fracture fixation. However, to date, there is no golden standard in the treatment of proximal humeral fractures.

Since fractures of the proximal humerus account for approximately 4–5% of all fractures, these can be regarded as relatively frequent injuries [1–3]. Of these, about 13–16% are three or four fragment fractures, and they occur predominantly in elderly patients for whom an important predisposing factor is often osteoporotic bone alteration. The therapeutic procedure depends not only on the classification of the fracture and concomitant injuries, but also on the biological age, bone structure, and individual needs of the patient [4]. Apart from the large proportion of fractures that can be treated non-operatively (only slightly or non-dislocated fractures for which non-operative stable reduction is possible), there is no general consensus on indications for operative treatment. Surgeons can choose from a great variety of procedures [5–10], whereby the results vary widely with regard to functional outcome, fracture healing, and incidence of humeral head necrosis [11, 12].

Problems arise (particularly for severely dislocated fractures) due to the atypical vascular system of the humeral head [13], which contributes to an inherent risk of encountering partial or total necrosis of this area. This risk of this type of complication depends, on the one hand, on the type of fracture and, on the other, on the treatment protocol. It has been estimated to be up to 40% by Kuner and co-workers [14] based on the evaluation of the results of an AO International study in which patients were treated with various osteosynthesis procedures; however, the proportion of three- and four-fragment fractures was higher than average in this study.

Minimally invasive techniques often do not achieve adequate stability for undertaking physiotherapeutic exercises, since the implants do not find sufficient purchase in osteoporotic bone (e.g., wire fixation). Adequate stability has so far only been achieved by an open operative procedure with fracture stabilization based on compression. This is often associated with further compromise of the residual vascularity.

The aim of the prospective study reported here was to evaluate the results of fracture treatment of proximal humerus fractures after open reduction and operative treatment with a new proximal humeral intramedullary nail (the proximal humeral nail, PHN) in terms of functional outcome, fracture healing, and the number of complications that occur (especially humeral head necrosis).

Materials and Methods

Patient Recruitment

This was a prospective, multicenter (11 trauma units from 11 medical centers; Table 1) case-series that recruited 151 patients between November 2002 and November 2006 who had the same number of fractures with non-displaced and displaced proximal humerus fractures undergoing osteosynthesis with an intramedullary PHN. The inclusion of new patients ended in September 2005, and the last 1-year follow-up examination was performed in November 2006. The mean

Table 1. List of participating clinics.

Clinic	Code
Universitätsklinik Mainz, Germany	MAI
Johannesburg Hospital, South Africa	JOH
Vogtlandklinikum Plauen, Germany	PLA
University Hospital Padova, Italy	PAD
Unfallkrankenhaus Meidling Vienna, Austria	WIE
Stadtkrankenhaus Worms, Germany	WOS
University Hospital Leuven, Belgium	LEU
Royal Liverpool University Hospital, UK	LIV
Centro Traumatologico Ortopedico Firenze, Italy	FIR
Universitätsklinik Bonn, Germany	BON
Kardinal Schwarzenbergisches Krankenhaus, Austria	SCH

number of patients recruited at each clinic was 14 (range 4–23).

Patients with two- and three-fragment proximal humerus fractures were included in this study if they had a mature skeleton and a maximal delay between accident and surgery of 10 days. The mean age of all patients was 63 years (range 16–97 years). There were 114 women (75%) with a mean age of 66 years (range 22–97 years), who were significantly older than the 37 recruited men (25%) (mean age 55 years, range 16–96 years).

Ninety-six patients reported at least one concomitant disease or disorder at baseline. Exclusion criteria were pseudarthrosis, pathological fractures and re-fractures, open fractures, or concomitant ipsilateral fractures of the distal humerus and/or elbow joint. Also excluded were patients with existing disorders having a relevant effect on the healing process, such as multiple sclerosis, paraplegia, or other relevant neurological disorders, as well as polytraumatized patients with an Injury Severity Score (ISS) > 16 or patients with pre-existing plexus injury or nerve palsy. Finally, any additional patients with a previous knowledge of their incapacity to attend follow-up appointments as well as pregnant or alcohol/drug/medication-dependent patients were also not included.

Implant

The implant used was a PHN made of titanium-alloy, with diameters of 7.5 or 8.0 mm and a length of 150 mm (Synthes GmbH Oberdorf, Switzerland). The nail is proximally interlocked with a spiral blade, where an end cap compresses on the blade inside the nail in order to achieve angular stability. Two distal bolts and one proximal oblique bolt have to be placed from lateral to medial.

Strong sutures can be fixed at the base of the spiral blade to achieve tubercle or rotator cuff fixation.

Operative Technique

The participating surgeons had different levels of experience with proximal humeral nailing in that some were more experienced in plating and others in nailing; a number of surgeons used most techniques frequently. To ensure that each surgeon had acquired a reasonable technical level, every surgeon had to perform at least five nailing procedures with the PHN prior to entering this study.

Surgery was performed on a radiolucent table with the patient positioned in a modified lateral position and side placement of the C-arm to allow for full viewing of the entire humerus in the antero-posterior (AP) and lateral views. Through an anterior–lateral acromial and through the raphe separating the anterior and middle third of the deltoid, a stab incision through the rotator cuff was performed. The humeral head was centrally perforated with an awl just medial of the insertion of the supraspinatus tendon. If necessary, K-wires were inserted into the humeral head to enable manipulation via radiographic control. Under image intensification, the surgeon then inserted the nail until the proximal end was slightly countersunk beneath the superior surface of the proximal humerus. For insertion of the spiral blade, a lateral incision through the skin adjacent to the tip of the trocar was created, and fibers of the deltoid muscle were spread apart. After the positioning of the blade with a guide wire in both AP and lateral views had been verified, the lateral cortex was perforated, and the cannulated tip of the blade was passed over the guide wire, advancing the blade through the nail with light, controlled blows of a hammer and radiographic monitoring. After distal interlocking with the aiming device, an end cap closed the nail base and fixed the spiral blade. In several cases, additional sutures fixed the major tubercle at the blade's base.

Baseline Evaluations, and Follow-up Examinations

At the 3- and 6-month and 1-year follow-up examinations, 130 (88%), 116 (79%), and 113 (77%) patients and fractures were examined, respectively. Thirty-eight patients were lost at the 1- year follow-up: four patients died of unrelated causes and the remaining 34 could not be contacted or refused to come to the treating clinic for further examination.

During the hospitalization period, the patients' demographics (i.e., gender, age, dexterity, smoking, concomitant diseases, and medication) and baseline characteristics (i.e. accident type, energy level of trauma, concomitant injuries, fracture classification, delay between accident and surgery, operation time, c-arm counter time, additional implants and sutures, additional medication, type and duration of immobilization, and beginning of active assisted and unrestricted mobilization) were documented. Patients were interviewed to determine their upper limb function 1 week before the accident and their pre-accident Disabilities of the Arm, Shoulder, and Hand (DASH) score using the extended three-modular questionnaire [15]. Fractures were classified according to the AO- and Neer classification [16, 17] by the treating surgeons. Intraoperative complications, such as bleeding, hematoma, and nerve injury, were documented. Patients were X-rayed in the AP projection and in Neer's view upon admission in the Emergency Room and postoperatively. Additional computed tomography (CT) evaluation was undertaken at the discretion of the treating surgeon.

Patients were actively followed-up after 12 weeks, 6 months, and 1 year. At each follow-up, the patients were X-rayed in two planes (i.e., AP and Neer's classification) to assess fracture healing and determine the possible occurrence of complications. Anticipated postoperative complications during follow-up included loss of reduction, fragment dislocation, axis deviation, head necrosis, or implant problems, such as screw perforation, screw loosening or backing-out, and plate pull-out or breakage, as well as surgical and other local or general complications, such as wound infection, soft tissue problem, or death. Reported complications and related patient radiographs were reviewed by the principal investigator to determine whether the complications occurred due to the implant, deficient technical procedure, general surgical conditions, bone quality and fracture-specific problems, or the patients' general condition.

Patients were further interviewed on their pain and shoulder mobility, and they were clinically examined using three power measurements for both shoulders in abduction to obtain individual Constant scores [18] of the injured and contralateral shoulder. Additionally, DASH and Neer scores were determined at the 1-year follow-up, at which time the range of motion was indicated in categories provided by the Neer score. All complications were documented throughout the postoperative period.

Data Management and Statistical Analyses

Study monitoring, database management, and statistics were carried out by a central monitoring organization. The mean of all Constant scores of the contralateral healthy side measured at any follow-up time was taken as the reference value for each patient. The Constant scores of the injured side at each follow-up were compared to that mean healthy Constant score and expressed in percentages.

Results

Preoperative

The mean DASH score referring to upper limb function 1 week before accident was 5.9 (range 0–63) with 62% (93/151) of patients having a zero DASH score. Higher pre-injury DASH scores were observed in patients > 90 years of age.

One hundred and twenty-three patients (81%) sustained a low-energy trauma and 65 patients (43%) injured their dominant arm. Most accidents happened at home, but a proportion also occurred as a result of either a road accident or during various sports and leisure activities.

According to the AO classification, 72 (48%) of all proximal humeral fractures were A fractures, 67 (44%) were B fractures, and 12 (8%) were C fractures. Both men and women more often sustained B1 fractures and, in general, there was no significant gender difference for all other fracture types (Fisher's exact test, $p = 0.121$). In patients ≤ 40 years of age, type B fractures represented 37% of the fracture types, with a similar proportion (33%) also occurring in the oldest age group (> 80 years of age). This trend was also similar for type A fractures, where 63 and 61% of these fractures were observed for the youngest and oldest age categories, respectively. However, type C fractures were not prevalent in any patient group, with only a maximum of 10% (4/39) occurring in the age group of > 40–60 years.

One hundred and forty-two fractures (94%) resulted from an isolated trauma. According to the Tscherne classification for closed soft tissue injuries, 21 (14%) and nine (6%) injuries were classified as type C I and type C II, respectively.

Fracture Treatment

Thirty-eight surgeons performed 151 osteosynthesis procedures of proximal humeral fractures with PHN. The patients were treated, on average, 3 days after their accident (range 0–10 days). A third of the patients were operated on 1 day after the trauma, and more than 60% were operated within 3 days. There was no significant difference in the average time to surgery among Type A, B, and C fractures, among two-, three-, and four-fragment fractures, and between iso-

Table 2. Additional implants used in conjunction with the proximal humeral nail.

Additional implants used	Number of surgeries
1–2× Screws	8
1–2× Cannulated screws	2
1–2× 4.0-cm/410-mm Titanium (cannulated) screws	13
2 K-wires + 1 Orthofix external fixator	1
ChronOS Inject	5
2× Distal locking	1
1× 3.5 Cancellous screw for fixation of the greater tubercle	1
Other	1

lated and multiple trauma patients (Kruskal–Wallis test $p = 0.24$, 0.26 and 0.45, respectively).

The mean duration of the performed surgeries was 50 min (range 7–130 min), with a significant increase in mean duration for fracture type A (47-min increase) and fracture type C (54-min increase) (Kruskal–Wallis test $p = 0.038$).

Closed reduction was achieved in 85% of the fracture cases; a small proportion of patients underwent a closed, open, or a combination of closed/open reduction technique with the use of additional tools, which mainly included the use of an elevator ($n = 14$). Most of the fractures were commonly fixed with a nail 7.5 mm in diameter (66%) and a spiral blade length of between 42 and 46 mm (15–20%). A total of 106 (70%) fractures were also locked with an additional oblique configured bolt.

Treatment in 32 fractures (21%) demanded an implant in addition to the PHN (Table 2), of which 52% were plate-independent screws [2]. Thirty fractures (20%) were treated with an additional suture, of which a non-resorbable suture was used in 21 cases (14%). Overall, 53 fractures (35%) required additional implants/sutures specifically for fixation of the proximal humerus anatomy, where the major proportion (81%; 43/53) of those interventions included an extra implant/suture of the greater tuberosity only.

One-hundred and twenty-nine (85%) patients were immobilized in a sling or brace. The mean length of immobilization in these patients was 11 days (range 1–30 days). Patients were permitted to start passive/active-assisted shoulder mobilization 8 days after surgery (range 1–30 days). Unrestricted mobilization was allowed after 18 days (range 1–60 days).

Complications and Reported Adverse Events

The total number of intraoperative complications documented for PHN was low and involved only four cases that occurred as a result of problems experienced with the surgical technique. These included one case of bleeding/hematoma, two cases of perforation to the articular surface by the oblique bolt, and one case in which the positioning of an additional screw was incorrect. These complications were considered to be only mild to moderate in severity, although the implants in two patients were removed.

In terms of postoperative complications, 22 occurred within the initial 3 months after PHN implantation. Thirty (63%) and ten (21%) of the total 48 reported complications were considered to be 'unrelated' and 'unlikely to be related' to the implant, respectively. Half of the complications ($n = 24$) were assessed as 'mild' in terms of the severity of their effects on the patient. Of the 48 complications reported, 54% (26/48) required another operation to rectify the problem, where removal of the entire original PHN configuration (with or without replacement) was undertaken in 69% (18/26) of these cases. Only three patients with multiple postoperative complications occurring throughout the follow-up visits were reported with severe four-part fractures.

The majority of postoperative complications ($n = 30$, 63%) were implant/surgery problems, in which secondary impaction of the humeral head ('cut through') ($n = 13$), perforation of the articular surface ($n = 9$), and implant loosening ($n = 4$) were prevalent; these occurred mostly in combination with events such as loss of reduction, dislocation of fragments, loosening of additional screws, delayed union, and partial/total avascular necrosis. These last six implant/surgery complications were categorized under 'other', and all stemmed from either incorrect positioning of the spiral blade ($n = 3$), of parts of the spiral blade ($n = 1$), or an additional screw ($n = 1$) as well as incorrect evaluation of the entire surgical procedure by the surgeon for the last patient.

For those patients with bone/fracture complications, loss of reduction was experienced in three patients (two of whom required re-operation) and four additional patients experienced either a non-union ($n = 2$) or partial/total avascular necrosis of the humeral head ($n = 2$). The remaining bone/fracture complications ($n = 4$) included one dislocation of fragments (and biceps impairment followed by malunion), one delayed union, pain combined with functional limitation of the shoulder (one patient), and a new fracture of the humeral diaphysis below the implant that occurred as a result of a patient falling within the first 3 months after surgery.

Only two complications attributed to the soft tissue/wound category occurred, with one case of radial nerve paralysis in the main joint of the left hand and one case of a local wound abscess. A small series of general complications were also documented, including four deaths from stroke, cardiovascular failure, and old age; all of these adverse events were considered to be purely associated with the patient and not to their participation in this study. The last general postoperative complication was reported as a problem with the 'too large' implant and the patient's diminutive anatomy.

Healing and Anatomical Restoration

The number of united fractures increased from 65 (50%) at the 3-month follow-up to 96 (83%) at the 6-month follow-up. At the 1-year follow-up, 111 (99%) fractures were united. At 6 months, only two delayed union fractures were reported of which one was classified as a 'non-union' at the last follow-up, and the other could not be re-evaluated because the patient was lost at this last examination time point.

The proportion of radiologically evaluated 'stable' fractures was 88 (114/130), 88 (100/114), and 96% (109/113) at the 3-, 6-month, and 1-year follow-up examinations.

For those fractures described as 'unstable' during any of the three follow-up examinations, four patients were reported with a loss of reduction and eight cases of perforation of the articular surface by screws were reported. Another 12 patients experienced secondary impaction of the humeral head, and four were diagnosed with a dislocation of fracture fragments of the greater tuberosity (n = 2) and lesser tuberosity (n = 2).

In addition, 33 (22%) patients were reported as having varus, valgus, recurvation, antecurvation, or other deformities throughout the follow-up periods. Specifically, two patients had valgus deformations of 15° and 40° at the 3-month follow-up, and 18 patients had varus deformations ranging from 5° to 35° (mean 19°) occurring at the 6-month and 1-year follow-up examinations; three patients experienced antecurvation of about 30° at the 3-month follow-up, and one recurvation of 5° was reported at 6 months. Other deformities were reported in 12 cases and included malpositioning of the greater tuberosity, impaction, translation, posterior calcifications, and partial humeral head necrosis.

Constant Score

The Constant score increased significantly between the 3- and 6-month follow-up periods by approximately 10 points ($p < 0.0001$), and this significance also held true for the difference of 7 points that occurred between the 6-month and 1-year follow-ups.

The function of the injured shoulder measured as a ratio between the Constant score of the injured shoulder and that of the contralateral healthy shoulder increased approximately 20% between the 3-month and 1-year follow-up, reaching 89% of the contralateral side after 1 year. There was no significant decrease in Constant scores (relative to healthy shoulder) from fracture types A to type C across the follow-up examinations [repeated-measure analysis of variance (ANOVA) $p = 0.28$]. However, a significant difference was observed between the age categories ($p = 0.0004$). There was a highly significant correlation between the Constant and Neer scores at the 1-year follow-up examination ($n = 97$; $r = 0.81$; $p < 0.0001$). The distribution of Constant scores per Neer classification of displaced fractures showed no significant difference in terms of median values at the 1-year follow-up ($p = 0.40$).

Neer Score

At the 1-year follow-up, the mean Neer score from 110 patients was 84.2 (range 22–100). Fifty-eight patients (53%) showed 'excellent' results (≥ 90 points) according to the Neer score category, and another 20 patients had 'satisfactory' results (18%). There was a highly significant negative correlation between the Neer and DASH scores at the 1-year follow-up examination ($n = 110$; $r = -0.77$; $p < 0.0001$).

DASH Score

The DASH score significantly increased between 1 week before the accident and the 1-year follow-up, with a mean difference of 5 points [95% confidence interval (CI) 2.3–8.0; $p = 0.0005$]. A significantly higher proportion of patients moved into higher DASH score categories between baseline and the 1-year follow-up (Symmetry test $p = 0.0003$). A deterioration of the DASH score of more than 15 points at the 1-year compared to their pre-injury score was recorded form 15 patients (13%). The distribution of DASH scores per Neer classification of displaced fractures showed a higher median value for four-part fractures, with involvement of the greater and lesser tuberosity at the 1-year follow-up.

Range of Motion

One year after surgery, the mean active forward flexion was 141° (range 45°–180°), active abduction was 135° (range 45°–180°), passive external rotation was 59° (range 0°–90°), and passive internal rotation was 75° (range 30°–90°). Patients could improve the range of motion of injured shoulders, performing almost as well as contralateral healthy shoulders after 1 year [3].

Overall, the range of motion significantly improved for any movement between the follow-up visits ($p < 0.006$). Table 3 presents the data on the mean range of motion of the injured and contralateral shoulders at the follow-up visits.

Return to Work

Thirty patients (91% of the 33 patients who worked before the accident) returned to work within 1 year, whereas three patients did not return – one actively chose to retire as a direct result of the injury, another retired for reasons other than those related to the fracture, and the third patient became unemployed following the operation. After 3 and 6 months, approximately 65 and 85% of patients could return to work, respectively.

Discussion

The treatment of proximal humeral fractures is still far away from a golden standard. This significant lack of one universal approach is due to a complicated assembly of different factors that are difficult to address in a single treatment option, whether it is a conservative regimen or an operative procedure with a single implant type. These factors arise, on one hand, from the patient him/herself (age, gender, health status and concomitant diseases, motivation, personality, personal, social and work-related expectations) and, on the other hand, from such biological factors as osteoporosis, vascularity, and endocrine constellation.

The proposal of using intramedullary nails for this fracture entity had been criticized not only because severe doubts exist on the capacity of these nails for providing sufficient stability [19], but questions on biological risks, such as damage to the axillary or the radial nerve, also remain unanswered [20].

The development of long humeral nails with an interlocking option, which enables stabilization of the ipsilateral proximal and diaphyseal humeral fractures, has demonstrated that there is also an indication for nailing proximal humeral fractures [21, 22]. Different interlocking modalities are available, with angle stable multidirectional screws [22] or angle stable spiral blades [21] being the most commonly used ones. From this development, it was only a short step to the development of pure short proximal humeral nails, which may be able to be interlocked distally as well under the guidance of an aiming device in a secure position, distant enough to the radial and median nerve.

Our results represent the outcomes of surgical procedures aimed at stabilizing proximal humeral fractures with the PHN, which were based on the principle of an angle stable spiral plate fixation in the humeral head (Figure 1).

The study data clearly show the limits of the procedure: C-type fractures were much more likely to show low outcome values, a higher rate of non-anatomical reduction, mal- or non-union, and avascular necrosis of the humeral head. Relative to A- and B-type fractures, C-type fractures more often require additional hardware for fixation, such as additional screws or tension band. In addition, for proper reduction and fixation, they need larger incisions and approaches. This, however, is not a new message: it is known from all fixation methods – including conservative treatment – that C-type proximal humeral fractures are more difficult to fix and that it is more

Table 3. Mean range of motion of injured and contralateral shoulders at the follow-up visits.

Injured and contralateral shoulders	n	Forward flexion[a]	Abduction[a]	External rotation[a]	Internal rotation[a]
Healthy contralateral shoulder[b]	137	163° ± 16.1	159° ± 20.7	67° ± 19.0	82° ± 11.8
Injured shoulder					
3 Months	130[c]	106° ± 37.8	98° ± 37.3	45° ± 26.8	63° ± 25.0
6 Months	116	129° ± 35.4	123° ± 38.3	49° ± 26.1	70° ± 21.5
1 Year	113	141° ± 34.0	135° ± 36.8	59° ± 23.7	75° ± 18.0
Ratio of injured/healthy shoulder					
3 Months	130[c]	65% ± 20.7	61% ± 20.6	66% ± 37.2	76% ± 25.7
6 Months	116	78% ± 18.8	77% ± 20.6	71% ± 27.8	84% ± 20.0
1 Year	113	86% ± 17.8	84% ± 19.0	87% ± 25.7	92% ± 17.4

Differences between follow-ups were significant for all parameters ($p < 0.006$)
[a]Mean ± standard deviation indicated
[b]Mean of contralateral values at any follow-up
[c]Number of observations for forward flexion was only 129

Figure 1. The proximal humeral Nail (PHN).

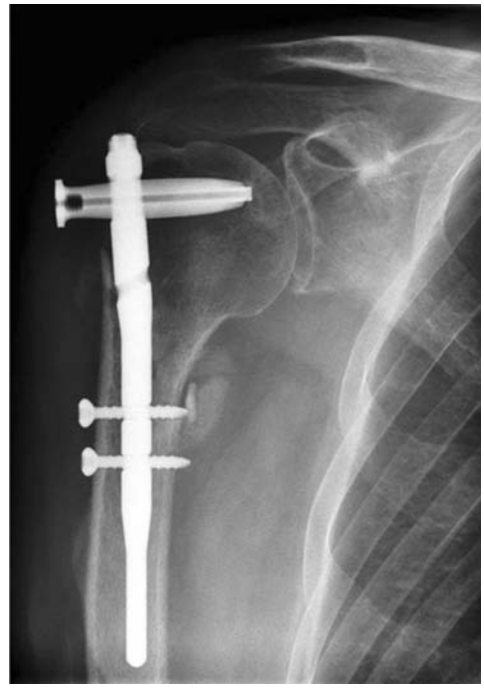

Figure 2. Suboptimal surgical technique – protrusion of the nail base with an end cap and of the spiral blade.

difficult to achieve the good results that are more common in A- or B-type fractures. Osteoporosis increases this difference even more.

These results show that a meticulous operative technique of proximal humeral nailing becomes even more important with increasing complexity of the fracture types and the higher degree of osteoporosis. An analysis of our study data reveals that in the majority of cases it was a weak operative technique that was responsible for treatment failure. Protrusion of the nail base produces impingement with pain and a poor range of motion (Figure 2), while placement of the spiral blade too proximal will weaken the construction, as will a too short blade. Blades that are too long will perforate and damage the glenoid (Figure 3). Introducing the nail too laterally will weaken the construction and increase the risk of rotator cuff damage when it perforates the insertion of the supraspinatus tendon.

Poor reduction and medial instability increases the risk of collapse and dislocation.

Within this context, a certain weakness of this study becomes evident: 38 surgeons operated on 151 fractures with the prerequisite that every surgeon had to perform at least five nailings with the PHN prior to

Figure 3. Suboptimal surgical technique. Perforation of the spiral blade and loosening of the proximal interlocking screw.

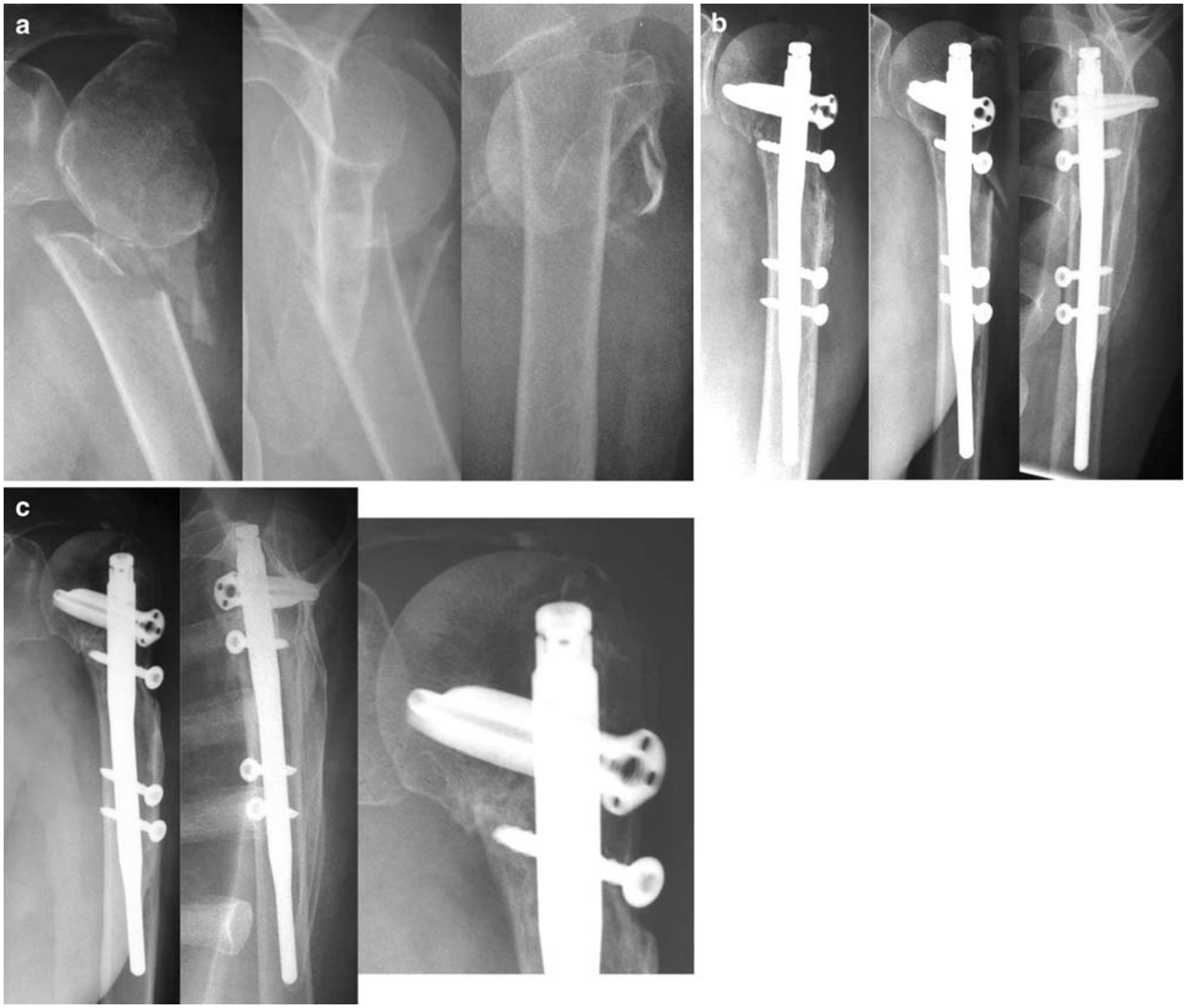

Figure 4. a Three-part fracture of the proximal humerus with metaphyseal comminution, b stabilization with PHN and spiral blade, c fracture healing after 4 months showing correct placement of the spiral blade and end cap.

entering this study. However, there had to have been different learning curves for different surgeons, and the complication rate would have been significantly lower in those having had a larger experience in antegrade nailing of the humerus.

Since this study is not designed to compare the angle stable nail with the angle stable plate for proximal humeral fractures, we are not able to compare these two implant classes. However, our subjective opinion is that this specific proximal humeral nail type should be used in situations that can profit from its intrinsic strength, i.e., in cases of small incisions and limited approaches. These are mainly A- and B-type fractures (Figure 4), possibly with good medial buttress. For C-type fractures, which are associated with the necessity of extending approaches and the desire for multi-directional fixation option, the angle stable plate is probably the better choice. Further development of innovative interlocking options for proximal humeral nails may enable this viewpoint to be changed in the future. It is even possible that other nail types exist even today that may enable good results even in C-type fractures.

Conflict of interest statement

The authors declare that there is no actual or potential conflict of interest in relation to this article.

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