Orthopaedics & Traumatology: Surgery & Research 100 (2014) 265–270

Available online at

ScienceDirect

www.sciencedirect.com

Elsevier Masson France

EM|consulte

www.em-consulte.com/en

Original article

Comparison of modified Hackethal bundle nailing *versus* anterograde nailing for fixation of surgical neck fractures of the humerus: Retrospective study of 105 cases

L. Milin [a,*], F. Sirveaux [b], F. Eloy [a], D. Mainard [c], D. Molé [b], H. Coudane [a]

[a] *Musculoskeletal Orthopedics, Trauma and Arthroscopic Surgery Department, CHU Nancy, hôpital Central, 29, avenue du Maréchal-De-Lattre-de-Tassigny, 54000 Nancy, France*

[b] *Centre chirurgical Émile-Gallé, 49, rue Hermite, 54052 Nancy cedex, France*

[c] *Orthopaedics and Trauma Surgery Department, CHU Nancy, hôpital Central, 29, avenue du Maréchal-De-Lattre-de-Tassigny, 54000 Nancy, France*

ARTICLE INFO

Article history:
Accepted 31 January 2014

Keywords:
Fracture fixation
Shoulder fracture
Intramedullary nailing

ABSTRACT

Introduction: Intramedullary fixation of displaced surgical neck fractures of the humerus can be performed either by retrograde pinning or anterograde nailing. The goal of the current study was to compare the postoperative reduction and stability obtained with these two techniques.
Hypothesis: Intramedullary nailing will provide the best reduction and stabilization of these fractures.
Patients and methods: This was a multicenter retrospective study that included patients with sub-tuberosity fractures with or without greater tuberosity fragment. These patients were treated either by retrograde Hackethal type pinning (group 1) or Telegraph anterograde nailing (group 2). To be included, patients needed to have A/P and lateral X-rays that had been taken before the surgery, immediately post-operative, between four and six weeks post-operative, and at the last follow-up. The outcomes were head angulation, translation and greater tuberosity position.
Results: One hundred and five patients (40 retrograde pinning and 65 anterograde nailing) with an average age of 69 years (18–97 years) were included. The pre-operative fracture displacement was similar between the two groups. After the surgery, the A/P head angulation had been corrected in 72.5% of patients in group 1 and 84% in group 2 (no significant difference). Translation was still present in 17.5% of patients in group 1 and 1.5% in group 2 ($P < 0.05$). At the last follow-up, union was achieved without residual angulation on lateral X-rays in 71% of patients in group 1 and 88% in group 2 ($P < 0.05$). The fractures had healed with residual translation is 19.5% of patients in group 1 and 3% in group 2 ($P < 0.05$).
Discussion and conclusion: In cases of displaced surgical neck fractures with or without a greater tuberosity fragment, anterograde nailing provides better reduction and stability than retrograde pinning. However, fixation of the greater tuberosity fragment must be improved.
Level of evidence: IV (retrospective comparative study).

1. Introduction

As the third most common type of fracture in those above 65 years of age, proximal humerus fractures will continue to increase in frequency as our population ages [1–3]. Sub-tuberosity fractures are the most common. Displaced fractures may require fixation using one of several techniques: percutaneous pinning [4,5], intrafocal (Kapandji) pinning [6–8], Hackethal type retrograde pinning [9], anterograde nailing [10,11] and plate-fixation [12–14]. Intramedullary fixation is less invasive because the fracture site does not need to be extensively dissected [15,16]. Among intramedullary methods, retrograde pinning and anterograde nailing are used most often and have been extensively studied [17–20]. The deleterious effect of malunion of the lesser tuberosity [21–23] or humeral head fragment is well known [10,23,24].

The primary objective of this study was to compare the reduction and stability of the construct after retrograde bundle pinning or anterograde nailing. The secondary objectives were to compare

* Corresponding author. +33 (0)6 48 76 64 76.
E-mail address: loic.mil@gmail.com (L. Milin).

http://dx.doi.org/10.1016/j.otsr.2014.01.005
1877-0568/

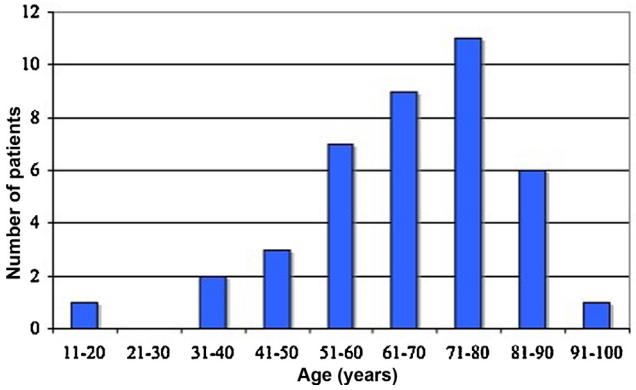

Fig. 1. Histogram of the age of patients receiving retrograde pinning.

the complication rate and final radiological outcomes between the two methods.

2. Patients and methods

2.1. Patients

We performed a multicenter retrospective study within three orthopedic surgery departments. The study inclusion period was from January 1, 2005 to December 31, 2009. We used data from the French Diagnosis-Related Group system to look for proximal humerus fractures treated by retrograde pinning (group 1) or by anterograde nailing (group 2). The following inclusion criteria were used: sub-tuberosity fracture with or without greater tuberosity fragment, availability of X-rays taken before the surgery, immediately postoperative, 4–6 weeks after surgery and at the final follow-up. Each technique's complications were recorded. Patients were excluded if they underwent early surgical revision to remove or change the fixation hardware.

One hundred five records were retained (85 women, 20 men) with the average age of patients being 69 years (range 18–97). The fracture occurred in the left shoulder in 55 cases (52%) and on the dominant side in 50 cases (48%). A greater tuberosity fragment was present in 35 fractures. Retrograde pinning was used in 40 fractures. The greater tuberosity was involved in 10 of these cases (25%). The average age of these patients was 64 years (range 18–97 years; Fig. 1). Anterograde nailing was used to treat 65 fractures. The greater tuberosity was involved in 25 of these cases (38%). The average age of these patients was 71 years (range 37–95 years; Fig. 2).

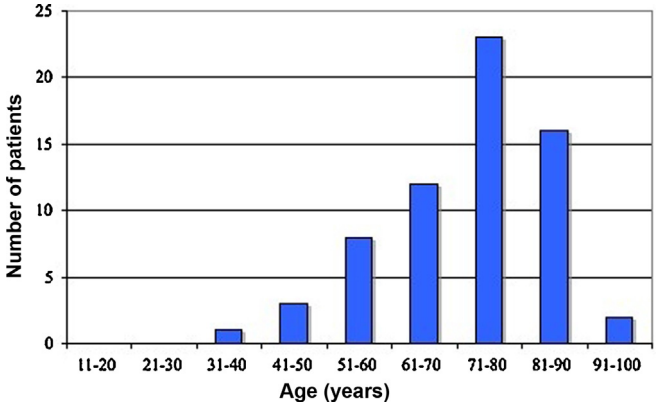

Fig. 2. Histogram of the age of patients receiving anterograde nailing.

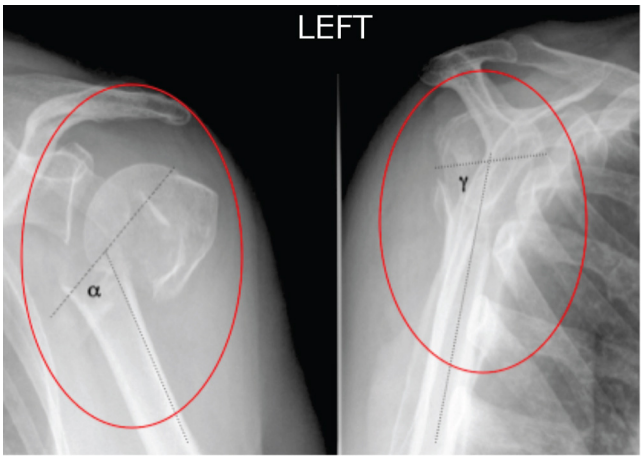

Fig. 3. Measurement of head angulation.

2.2. Surgical techniques

2.2.1. Retrograde pinning

This technique was based on Hackethal's principles [9] for shaft fractures as modified by Apprill and Boll for proximal fractures [25]. Patients were operated supine under general or regional anesthesia with upward traction applied to the arm. The image intensifier was placed horizontally at the patient's head. The fracture was reduced using external maneuvers. The pins were introduced by corticotomy 2–3 cm above the olecranon fossa. On average, five K-wires were used (range 3–8) with an average diameter of 2.2 mm (range 2.0–3.0). Average procedure time was 42 minutes (range 20–75). The elbow was immobilized against the body for an average of 2.5 weeks (range 0–4).

2.2.2. Anterograde nailing

First and second generation Telegraph Nails were used (FH Orthopedics, Heimsbrunn, France) [10]. The procedure was performed with the patient in a half-seated position and the image intensifier placed vertically above the patient. A transdeltoid anterolateral approach was used. In 31 cases (48%), a 9 mm diameter nail was used; in 20 cases (30%), an 8 mm diameter nail was used and in 14 cases (12%) a 7 mm diameter nail was used.

The nails were locked with the associated instrumentation. The head area was locked with two screws in 57 cases (88%) and three screws in eight cases (12%). The shaft area was locked with one screw in 39 cases (60%) and two screws in 15 cases (23%). Average procedure time was 44 minutes (range 20–75).

The elbow was immobilized against the body for an average of 2.5 weeks (range 0–6).

2.3. Methods

2.3.1. X-ray evaluation

The X-ray assessment consisted of two orthogonal views (A/P and Lamy lateral views). The inclusion criteria were verified on preoperative X-rays and CT scans when available (29% of cases). The outcomes were head angulation, epiphyseal translation and greater tuberosity displacement. An independent observer analyzed the X-rays.

On A/P views, the α angle was formed by the intersection of a line parallel to the shaft axis and a line passing through the anatomical neck. On lateral views, the γ angle was determined using the same method (Fig. 3). The head was considered anatomically positioned when the α angle was between 30° and 60° (45° ± 15°). Valgus was defined as anα angle greater than 60°; varus was defined as anα

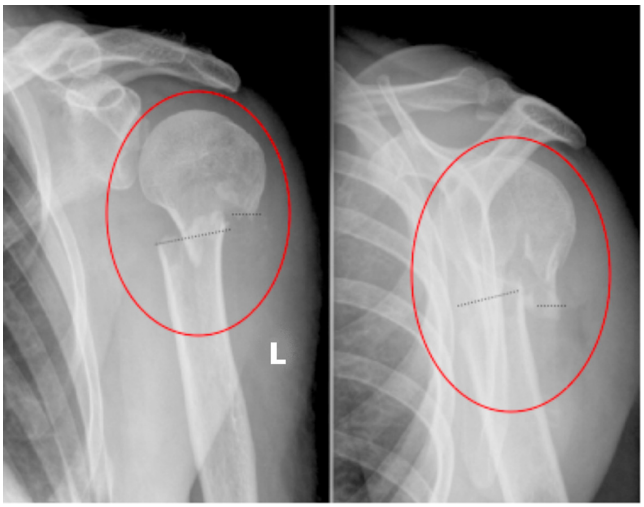

Fig. 4. Measurement of translation.

angle less than 30°. The head was considered anatomically positioned when the γ angle was between 45° and 75° (60° ± 15°). Anteversion was defined as a γ angle greater than 75°; retroversion was defined as an angle less than 45°. These values were chosen based on published data [8,24–28].

Epiphyseal translation was measured relative to the A/P and lateral diameter of the metaphysis [29] (Fig. 4). Translation was graded as minimal (<33%), moderate (33–66%) and significant (>66%).More than 5 mm displacement of the lesser tuberosity on A/P or lateral views was considered significant [8,26,30] (Fig. 5). Reduction of the angulation was deemed satisfactory if the α angle was between 30° and 60°, the γ angle was between 45° and 75°, translation was less than 33% and residual lesser tuberosity displacement was less than 5 mm.

Secondary displacement was defined as more than 10° head angulation, more than 10% translation or more than 5 mm lesser tuberosity displacement relative to the post-operative X-rays. At the last follow-up, the same criteria were used to analyze fracture union: A/P head angulation ($30° < \alpha < 60°$) and lateral head angulation ($45° < \gamma < 75°$); translation less than 33%; lesser tuberosity displacement less than 5 mm.

2.3.2. Statistical analysis

The study data were collected in an Excel® spreadsheet and analyzed with Staview® software. The Chi-square test was used to evaluate quantitative variables in contingency tables. Quantitative and qualitative variable were compared using simple regression, Fischer's, Student's and Bartlett's tests. Kruskall-Wallis non-parametric tests were used when the homogeneity of variances assumption was not met and when the data were not normally distributed. The results were evaluated using a 5% alpha risk.

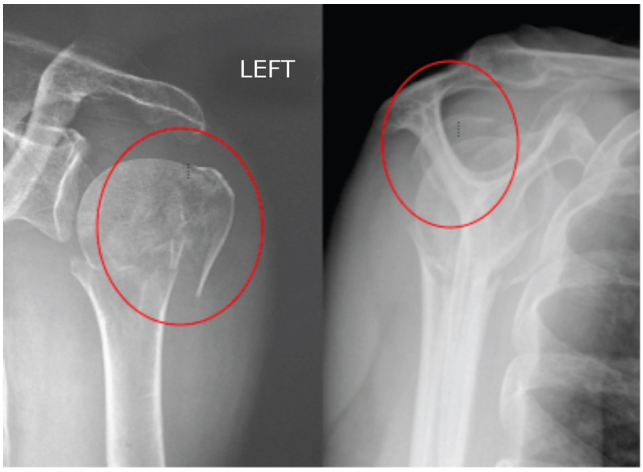

Fig. 5. Measurement of lesser tuberosity displacement.

3. Results

3.1. Complications

In group 1, there was one case of transient axillary nerve paralysis, 11 of proximal pin migration (27%) and 11 of distal pin migration (27%). At the last follow-up, two cases of osteonecrosis (5%) and one case of non-union (2.5%) were observed. There were 26 retrograde pinning-related complications (63%) that required early revision in three cases (7.5%) and hardware removal in 16 cases (39%) at an average of 8.5 months (range 1.5–15).

In group 2, there was one broken screw and two cases of intraoperative shaft fracture. During the follow-up period, there were four cases of broken screws (6%), four of screw movement (6%) and eight of screw projection (12%). At the last follow-up, there were three cases of osteonecrosis (4.5%). There were 22 nailing-related complications (34%) that required early revision in two cases (3%) and hardware removal in nine cases (14%) at an average of 11 months (range 3–48). The complication rate and re-operation rate were significantly higher in group 1 than in group 2.

Of the 105 patient records that met the inclusion criteria, four were excluded because of early surgical revision. The K-wires were removed in one patient; two patients were revised with a reverse shoulder arthroplasty and one with plate fixation. As a consequence, the X-rays were analyzed from 101 records (38 retrograde bundle pinning and 63 anterograde nailing).

3.2. X-ray evaluation

3.2.1. Initial displacement

Overall, 34% of cases had varus displacement, 32% had valgus displacement and 52% had retroversion. The translation was noted as being significant in 10% of cases on A/P views and 16% on lateral views. When the fracture line went through the tuberosity, the greater tuberosity was significantly displaced in 23% of cases on A/P views and 46% on lateral views. There were no significant differences between the two groups. A/P head angulation was present in 78% of group 1 fractures and 59% of group 2 fractures. Retroversion was present in 61% of group 1 fractures and 49% of group 2 fractures. A/P head translation was considered significant in 10% of group 1 fractures and 9% of Group 2 fractures. Lateral head translation was considered significant in 49% of group 1 fractures and 37% of group 2 fractures. In group 1, the greater tuberosity was displaced on A/P views in 20% of cases and on lateral views in 49% of cases. In group 2, it was displaced on A/P views in 24% of cases and on lateral views in 38% of cases.

3.2.2. Postoperative reduction

In group 1, the angulation was reduced in 72.5% of cases on A/P and 85% on lateral views. Moderate or significant translation was still present in 17.5% of cases on A/P and 15% on lateral views. When a tuberosity fragment was present, the greater tuberosity was reduced in 92% of cases on A/P and 70% on lateral views. In group 2, the angulation was reduced in 84% of cases on A/P and 83% on lateral views. Moderate or significant translation was still present in 1.5% of cases on A/P and 3% on lateral views. When a greater tuberosity fragment was present, it was reduced in 80% of cases on A/P and 67% on lateral views. There were no significant

differences between groups in terms of reduction of head angulation. The translation was better reduced in group 2 on both A/P and lateral views ($P < 0.05$). Anterograde nailing did not result in better greater tuberosity reduction.

3.2.3. Appearance at the first follow-up (4–6 weeks)

In group 1, the angulation was worse in 38.5% of cases on A/P and 36% on lateral views, while translation was present in 15% of cases on A/P and 8% on lateral views. We found no signs of lesser tuberosity displacement. In group 2, the angulation was worse in 33% of cases on A/P and 20% on lateral views, while translation was present in 14% of cases on A/P and 11% on lateral views. When a greater tuberosity fragment was present, it was more displaced in 9% of cases on A/P and 23% on lateral views. There was no significant difference between groups in terms of frontal plane stability. Nailing was better at ensuring humeral head stability on lateral views, but this difference was not statistically significant ($P = 0.07$). The two methods were equally effective at maintaining stability in translation. Anterograde nailing did not result in better greater tuberosity stability.

3.2.4. Final follow-up

In group 1, the α angle was satisfactory in 72% of cases, and the γ angle in 71% of cases.

Translation persisted in 12% of cases on A/P view and 7.5% on lateral view. When a greater tuberosity fragment was present, malunion was visible in 10% of cases on A/P and 20% on lateral views. Fifty-five percent were anatomically positioned based on all the criteria.

In group 2, the α angle was satisfactory in 71% of cases, and the γ angle in 88% of cases.

Translation persisted in 1.5% of cases on A/P view and 1.5% on lateral view. When a greater tuberosity fragment was present, malunion was visible in 12% of cases on A/P and 36% on lateral views. Fifty-four percent were anatomically positioned based on all the criteria.

Bone union without A/P head angulation and without residual translation was more common in group 2. These differences were significant ($P < 0.05$). There were no visible differences for the greater tuberosity fragment.

4. Discussion

The proximal humerus was anatomically reconstructed in only half of the cases reviewed. Malunion was mainly the result of poor intra-operative reduction. In both techniques, reduction was performed with external manipulations under fluoroscopy guidance. By positioning the patient supine with traction on the arm during retrograde pinning, it is easier to rotate the image intensifier around the arm to obtain images in both planes, however this limits which external manipulation are possible, especially to reduce translation. During the anterograde nailing procedure, the patient's semi-seated position frees up the arm and makes it easier to preform manipulations to reduce the fracture. This could explain why better reduction of translation was obtained with this technique. The drawback of this semi-seated position is that the arm must be abducted to take lateral views, which is not possible because of the size of the nail instrumentation. Neither technique was able to stabilize the fracture site, because secondary head angulation was observed in the frontal plane in both groups. However, the stability in the sagittal plane was slightly better in group 2 than in group 1, as there were fewer cases of residual head angulation on lateral views. At the last follow-up, anterograde nailing also resulted in fewer cases of residual translation.

There are no published biomechanical studies comparing these two techniques. A recent cadaver study has shown that locking plates are theoretically better at stabilizing sub-tuberosity fractures than nailing [31]. However these theoretical advantages were not found in clinical studies [32]. One prospective, randomized study found a significantly greater complication rate with locking plates than with nailing (31% *versus* 4%) [33].

The current study only evaluated the quality of fracture reduction and displacements on X-rays, and did not evaluated clinical outcomes. Several studies have shown that malunion, especially in the sagittal plane, has a detrimental effect on clinical outcomes [10,22,26,34]. Court-Brown et al. [35] showed that more than 33% residual translation increases the risk of non-union and poor clinical outcomes.

The limitations of the current study revolve around the study population and methods. The average age was not the same in both groups: retrograde pinning 64 years, range 18–97; anterograde nailing 71 years, range 37–95. This difference was purely due to chance because patients were referred to one of the three participating departments according to the on-call schedule. The superiority of nailing was demonstrated in a group of patients that was older and had a greater risk of osteoporosis and secondary displacement. The reproducibility of the method used to measure displacements was not evaluated.

Only a few studies have evaluated retrograde pinning in this indication, but they did not evaluate radiological outcomes or secondary displacement [25,36–38]. The main reported complications were K-wire migration and intra-operative fracture at the entry point. Champetier reported K-wire migration into the joint in 5% of cases [37]. Bombart reported four cases (7%) of neurological complications [38], and nine cases of intra-articular K-wire migration (16%). Putz reported two cases (1.5%) of intra-operative fracture and 14 (10%) of K-wire protrusion [39]. Of the 54 patients with more than one-year follow-up, 12 had signs of K-wire migration (22%). Bombart found that perforation of subchondral bone and incorrect intra-operative impaction are risk factors for migration [38]. He recommended removing any migrated K-wires 60 days after the surgery; if they have not migrated, he recommended removing them after 90 days. During the 2003 SOFCOT symposium [40], this complication was imputed to insufficient filling of the medullary canal or lack of epiphyseal divergence. Speedy removal of the hardware was recommended. One study evaluated the effect of the number of K-wires and their position on migration risk in 31 cases of sub-tuberosity fracture [8]. When at least three K-wires were used in the upper part of the head and in three different areas, the divergence was labelled as satisfactory (15 cases). There were two secondary displacements (13.3%) in these 15 cases. When the divergence was insufficient (16 cases), there were more secondary displacements (6 cases or 37.5%). We did not specifically assess the position of the K-wires in the humeral head. Although an average of five K-wires was used, there were several cases of migrations, which often led to the K-wired being removed.

After anterograde nailing, Cuny [10] found an average α angle of 44° (10–70°), an γ angle of 37° (0–70°) and 2 mm residual lesser tuberosity displacement on average. Boughberi reported an average α angle of 38° and residual posterior angulation in 12% of cases [28]. Chassat [41] found that 63% of patients had anatomical reduction, with average loss of A/P reduction of 10° relative to post-operative X-rays. The current study is consistent with published studies, which confirms the lack of control over reduction at the time of nailing, and secondary displacements leading to head malunion in 30% of cases. However, secondary malunion of surgical neck fractures of the humerus is well tolerated as long as the angulation is not more than 45° and the joint is congruent [42]. Malunion of the greater tuberosity is a source of poor outcomes if it is displaced by more than 5 mm [23,24]. Proper reduction and stabilization of the tuberosity fragment is essential [21,36,39,43]. Le Bellec recommends performing an additional approach during

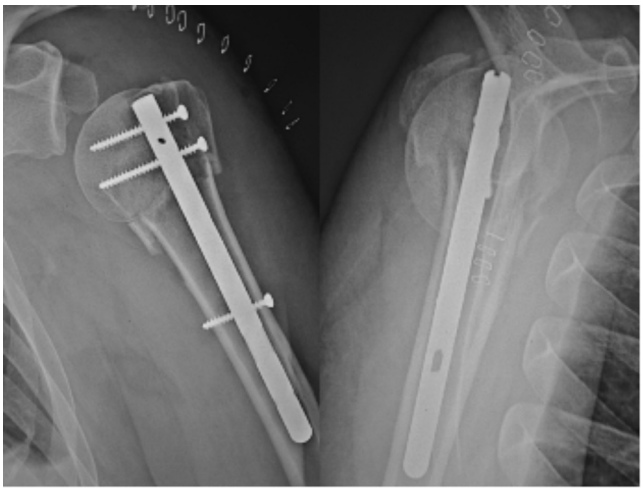

Fig. 6. The lesser tuberosity was not reduced by Telegraph nailing.

pinning. But this second approach is difficult to perform during retrograde pinning, as the patient's position would have to be changed. During anterograde nailing, reduction of the greater tuberosity can be ensured by lengthening the incision if necessary. Fixation can be ensured with screws through the nail or by transosseous suture fixation. In the current study, nailing was often insufficient to stabilize the greater tuberosity. This could be related to the frontal plane orientation of the screws, which does not provide perpendicular fixation to the tuberosity fracture line (Fig. 6). Changes to the proximal screw orientation have now been proposed.

The complications of nailing were the same as reported in other published studies. Cuny found a 26% rate of secondary impingement due to nail or screw movement [10,11,44]. Chassat found four case of telegraph nail projection (16%) and five cases of broken screws (20%) [41]. Boughebri described two cases of telegraph nail projection (6%) and four of screw movement (12%) [28]. Nail projection can be the result of a technical error or secondary displacement of the head segment. This complication is not well tolerated by patients and may require nail removal. The current study showed that the re-operation rate for hardware removal was significantly less after anterograde nailing than retrograde pinning (14% *versus* 39%). Intra-operative shaft fractures have not been reported in previously published studies. The two fractures (3%) in the current study occurred when a 9 mm diameter nail was used, thus we recommend against its use.

The shaft area was locked with one screw in 39 cases (60%) and two screws in 15 cases (23%). We did not specifically assess the effect of distal locking on stability. But this likely has an effect, as shown in a biomechanical study on cadavers, where 16 subtuberosity fractures were treated by nailing [45]. The initial fracture stability was improved by using distal locking screws.

5. Conclusion

Anterograde nailing was preferable to retrograde pinning for surgical neck fractures of the humerus, with or without tuberosity fragment. This technique provided better initial fracture reduction and more stable fixation. However, nailing was not able to reduce and stabilize the tuberosity fragment and the complication rate was high in these cases. The impact of changing the orientation of the epiphyseal screws during nailing must still be demonstrated.

Disclosure of interest

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

References

[1] Lauritzen JB, Schwarz P, Lund B, McNair P, Transbol I. Changing incidence and residual lifetime risk of common osteoporosis-related fractures. Osteoporos Int 1993;3:127–32.
[2] Bengner U, Johnell O. Changes in the incidence of fracture ofthe upper end of the humerus during a 30-year period. Clin Orthop 1988;231:179–82.
[3] Palvanen M, Kannus P, Niemi S, Parkkari J. Update in the epidemiology of proximal humeral fractures. Clin Orthop Relat Res 2006;442:87–92.
[4] Jaberg H, Warner J, Jakob P. Percutaneous stabilization of unstable fractures of the humerus. J Bone Joint Surg Am 1992;74:508–15.
[5] Resch H, Povacz P, Frohlich R, Wambacher M. Percutaneous fixationof three- and four-part fractures of the proximal humerus. J Bone Joint Surg Br 1997;79:295–300.
[6] Kapandji A. L'Ostéosynthèse par la technique des broches en palmiers des fractures du col chirurgical de l'humérus. Ann Chir Main 1989;8(1):39–52.
[7] Kapandji AI, Kapandji TG. Embrochage en palmier dans les traumatismes récents de l'épaule. Cahiers d'enseignement de la Sofcot, Expansion Scientifique française 1996;56:57–66.
[8] Le Bellec Y, Masmejean E, Cottias P, Alnot J-Y, Huten D. Ostéosynthèse des fractures de l'humérus proximal par brochage en palmier. Rev Chir Orthop 2002;88:342–8.
[9] Hackethal KH. Die Bundelnragefung. Berlin: Springer Verlag; 1961.
[10] Cuny C, Pfeffer F, Irrazi M, Chammas M, Empereur F, Berrichi A, et al. Un nouveau clou verrouillé pour les fractures proximales de l'humérus. Rev Chir Orthop 2002;88:62–7.
[11] Cuny C, Scarlat M, Irrazi M, Beau P, Wenger V, Ionescu N, et al. The Telegraph nail for proximal humeral fractures: a prospective four -year study. J Shoulder Elbow Surg 2008;17:539–45.
[12] Esser RD. Ostéosynthèse par plaque des fractures à trois et quatre fragments. Cahiers d'enseignement de la Sofcot 1996;S6:81–7.
[13] Koukakis A, Apostolou CD, Taneja T, Korres OS, Amini A. Fixation of proximal humerus fractures using the PHILOS plate: early experience. Clin Orthop Relat Res 2006;442:115–20.
[14] Rose PS, Adams CR, Torchia ME, Jacofsky DJ, Haidukewych GG, Steinmann SP. Locking plate fixation for proximal humeral fractures: initial results with a new implant. J Shoulder Elbow Surg 2007;16:202–7.
[15] Adedapo AO, Ikpeme JO. The results of internal fixationof three- and four-part proximal humeral fractures with the Polarus nail. Injury 2001;32:115–21.
[16] Agel J, Jones CB, Sanzone AG, Camuso M, Henley MB. Treatment of proximal humeral fractures with Polarus nail fixation. J Shoulder Elbow Surg 2004;13:191–5.
[17] Brianza S, Plecko M, Gueorguiev B, Windolf M, Schwieger K. Biomechanical evaluation of a newfixation technique for internalfixation of three-part proximal humerus fractures in a novel cadaveric model. Clin Biomech 2010;25:886–92.
[18] Hatzidakis AM, Shevlin MJ, Fenton DL, Curran-Everett D, Nowinski RJ, Fehringer EV. Angular-stable locked intramedullary nailing of two-part surgical neck fractures of the proximal part of the humerus. A multicenter retrospective observational study. J Bone Joint Surg Am 2011;93(23):2172–9.
[19] Pospula W, Abu Noor T. Hackethal bundle nailing with intramedullary elastic nails in the treatment of two- and three-part fractures of the proximal humerus: initial experience at Al Razi Hospital, Kuwait. Med Princ Pract 2009;18(4):284–8 [Epub 2009 Jun 2].
[20] Kosaka T, Yamamoto K. Long-term results after treatment of humeral neck fractures using modified Hackethal bundle nailing. West Indian Med J 2011;60(1):82–5.
[21] Neer CS. Displaced proximal humeral fractures: part 1: classification and evaluation. J Bone Joint Surg Am 1970;52:1077–89.
[22] Burton DJC, Watters AT. Management of proximal humeral fractures. Current Orthopaedics 2006;20:222–33.
[23] Gerber C, Hersche O, Warner JP. Place de l'ostéosynthèse dans les fractures complexes, Les traumatismes récents de l'épaule. Cahiers d'enseignement de la Sofcot, Expansion Scientifique Française 1996;56:104–17.
[24] Duparc F, Huten D. Le traitement conservateur des fractures de l'extrémité supérieure de l'humérus (Symposium Sofcot 1997). Rev Chir Orthop 1998;84(suppl. I):121–89.
[25] Apprill G, Boll P. Le traitement des fractures du col de l'humérus par embrochage centro-médullaire sans ouverture du foyer de fracture. Rev Chir Orthop 1968;54:657–66.
[26] Bahrs B, Rolauffs K, Dietz C, Eingartner K, Weise. Clinical and radiological evaluation of minimally displacedproximal humeral fractures. Arch Orthop Trauma Surg 2010;130:673–9.
[27] Hardeman F, et al. Predictive factors for functional outcome and failure in angular stable osteosynthesis of the proximal humerus. Injury 2011, http://dx.doi.org/10.1016/j.injury.2011.04.003.
[28] Boughebri O, Havet E, Sanguina M, Daumas L, Jacob P, Zerkly B, et al. Traitement des fractures de l'extrémité proximale de l'humérus par clou Télégraph. Rev Chir Orthop 2007;93:325–32.
[29] Court-Brown CM, Garg A, McQueen M. The translated two-part fracture of the proximal humerus. Epidemiology and outcome in the older patient. J Bone Joint Surg Br 2001;83–B:799–804.
[30] Koike Y, Komatsuda T, Sato K. Internal fixation of proximal humeral fractures with a Polarushumeral nail. J Orthopaed Traumatol 2008;9:135–9.

[31] Edwards L, Sara, Wilson A, Nicole, Zhang, Li-Qun, et al. Two-part surgical neck fractures of the proximal part of the humerus: a biomechanical evaluation of two fixation techniques. J Bone Joint Surg Am 2006;88-A(10):2258–64.
[32] Gradl G, Dietze A, Kääb M, Hopfenmüller W, Mittlmeier T. Is locking nailing of humeral head fractures superior to locking plate fixation? Clin Orthop Relat Res 2009;467(11):2986–93.
[33] Zhu Y, Lu Y, Shen J, Zhang J, Jiang C. Locking intramedullary nails and locking plates in the treatment of two-part proximal humeral surgical neck fractures: a prospective randomized trial with a minimum of three years of follow-up. J Bone Joint Surg Am 2011;93(2):159–68.
[34] Poeze M, Lenssen A-F, Van Empel J-M, Verbruggen J-P. Conservative management of proximal humeral fractures: can poor functional outcome be related to standard transscapular radiographic evaluation? J Shoulder Elbow Surg 2010;19:273–81.
[35] Court-Brown CM, McQueen MM. Nonunions of the proximal humerus: their prevalence and functional outcome. J Trauma 2008;64(6): 1517–21.
[36] Mouradian WH. Displaced proximal humeral fractures. Seven years experience with a modified Zickel supracondylar device. Clin Orthop Relat Res 1986;(212):209–18.
[37] Champetier J, Brabant A, Charignon G, Durand A, Letoublon C, Mignot P. Traitement des fractures de l'humérus par l'embrochage en bouquet. J Chir (Paris) 1975;109:75–82.
[38] Bombart M, Moulin A, Danan JP, Alperovitch R. Traitement par embrochage à foyer fermé des fractures de l'extrémité supérieure de l'humérus. Rev Chir Orthop 1978;64:221–30.
[39] Putz P, Ariaz C, Bremen J, Delvaux D, Simons M. Le traitement des fractures de l'épiphyse proximale de l'humérus par embrochage fasciculé selon Hackethal. Acta Orthop Belg 1987;53:80–7.
[40] Gayet LE, Freslon M, Nebout J. Traitement chirurgical : l'embrochage fasciculé. Rev Chir Orthop 2004;90(5):42–4.
[41] Chassat R, Guillon P, Dauzac C, Leroux R, Meunier C, Carcopino JM. Résultats de l'ostéosynthèse par clou télégraph des fractures complexes de l'humérus proximal chez le sujet de plus de 50 ans. Rev Chir Orthop suppl 2004;90:81.
[42] Keene JS, Huizenga RE, Engber WD, Rogers SC. Proximal humeral fractures: a correlation of residual deformity with long-term function. Orthopedics 1983;(6):173–8.
[43] Mestdagh H, Vigier P, Bocquet F, Butruille Y, Letendard J. Résultats à long terme du traitement des fractures-luxations de l'extrémité supérieure de l'humérus. Rev Chir Orthop 1986;72(suppl. 2):132–5.
[44] Cuny C, Darbelley L, Touchard O, Irrazi M, Beau P, Berrichi A, et al. Fractures à quatre fragments del'humérus proximal traitées par enclouage léger à vis autostables : à propos de 31 cas. Rev Chir Orthop 2003;89:507–14.
[45] Horn J, Gueorguiev B, Brianza S, Steen H, Schwieger K. Biomechanical evaluation of two-part surgical neck fractures of the humerus fixed by anangular stable locked intramedullary nail. J Orthop Trauma 2011;25:406–13.