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Displaced humeral surgical neck fractures: classification and results of third-generation percutaneous intramedullary nailing

Pascal Boileau, MD, PhD[a,*], Thomas d'Ollonne, MD[a], Charles Bessière, MD[b], Adam Wilson, MD[a], Philippe Clavert, MD, PhD[c], Armodios M. Hatzidakis, MD[d], Mikael Chelli, MD[a]

[a]*Institut Universitaire Locomoteur & Sport, Hôpital Pasteur 2, Côted'Azur University, Nice, France*
[b]*Clinique les Lauriers, Centre de Chirurgie, Fréjus, France*
[c]*Orthopédique et de la Main, Medical University of Strasbourg, Illkirch, France*
[d]*Western Orthopaedics, Denver, CO, USA*

Background: The high rates of complications and reoperations observed with the early designs of first-generation (unlocked) and second-generation (bent design) humeral intramedullary nail (IMNs) have discouraged their use by most surgeons. The purpose of this study was to report the results of a third-generation (straight, locking, low-profile, tuberosity-based fixation) IMN, inserted through a percutaneous approach, for the treatment of displaced 2-part surgical neck fractures.
Methods: We performed a retrospective review of 41 patients who underwent placement of a third-generation IMN to treat a displaced 2-part surgical neck fracture (AO/OTA type 11A3). The mean age at surgery was 57 years (range, 17-84 years). After percutaneous insertion through the humeral head, the IMN was used as a reduction tool. Static locking fixation was achieved after axial fracture compression ("back-slap" hammering technique). Patients were reviewed and underwent radiography with a minimum of 1 year of follow-up; the mean follow-up period was 26 months (range, 12-53 months).
Results: Preoperatively, 3 types of surgical neck fractures were observed: with valgus head deformity (Type A = 8 cases), shaft translation without head deformity (Type B = 19 cases), or with varus head deformity (Type C = 14 cases). At final follow-up, all fractures went on to union, and the mean humeral neck-shaft angle was 132° ± 5°. We observed 2 malunions and 1 case of partial humeral head avascular necrosis. No cases underwent screw migration or intra-articular penetration. At last review, mean active forward elevation was 146° (range, 90°-180°) and mean external rotation was 50° (range, 20°-80°). The mean Constant-Murley score and Subjective Shoulder Value were 71 (range, 43-95) and 80% (range, 50%-100%), respectively.
Conclusions: Antegrade insertion of a third-generation IMN through a percutaneous approach provides a high rate of fracture healing, excellent clinical outcome scores, and a low rate of complications. No morbidity related to the passage of the nail through the supraspinatus muscle and the cartilage was observed. The proposed A, B, and C classification allows choosing the optimal entry point for intramedullary nailing.

The study was approved by the Institutional Review Board of Institut Universitaire Locomoteur et du Sport (No. 2016-02).

*Reprint requests: Pascal Boileau, MD, Institut Universitaire Locomoteur & Sport, Hôpital Pasteur 2, University of Nice-Sophia-Antipolis, 30, Avenue de la Voie Romaine, Nice 06000, France.
E-mail address: boileau.p@chu-nice.fr (P. Boileau).

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The treatment of displaced 2-part surgical neck fractures remains controversial.[6,11-13,21-23,25,28,30-32,35,40,45,47,49,51-53,56,57] The most commonly used fixation option for 2-part fractures requiring surgical treatment is a locking plate and screw construct, although many complications related to this option have been reported throughout the literature. Complications associated with locking plates and an open approach for the treatment of proximal humeral fractures include humeral head necrosis (up to 35%), screw cutout (up to 57%) with potential glenoid erosion, and fracture nonunion (up to 13%).[2,8,18,27,41]

Antegrade intramedullary (IM) nailing for 2-part surgical neck fractures of the proximal humerus could be an alternative treatment option to locking plates. A recent prospective randomized trial comparing locking intramedullary nails (IMNs) and locking plates for the treatment of 2-part surgical neck fractures has shown that the complication rate was much higher for the locking plate group (31%) than the locking nail group (4%).[57] Biomechanical studies have also demonstrated the superiority of IM nailing over plating for 2-part surgical neck fractures.[7,15,17,24,54,55,58] Nevertheless, locking plate fixation of displaced surgical neck fractures is still favored by most surgeons.

The high rates of complications and reoperations observed with the early designs of first-generation (unlocked) and second-generation (bent design) humeral IMNs have discouraged their use by most surgeons.[1,39,44,48,50] The absence of secured mechanical locking for the proximal screws with the first generation of humeral IMNs has been a cause of screw migration with loss of reduction, as well as malunion.[13,14,33,39,43] Moreover, excessive nail diameter and length could lead to distal nail interlocking inside the humeral canal with distraction of the fracture site and surgical neck nonunion.

The poor results associated with the use of second-generation humeral IMNs also led surgeons to reject or abandon their use. The main reason is that the curved design of the second generation of humeral IMNs has been associated with iatrogenic rotator cuff tears.[33] "Violation" of the supraspinatus tendon insertion when introducing such a curved IMN inside the proximal humerus has led to a high number of patients complaining of shoulder pain and stiffness, as well as a high rate of unexpected reoperations.[1,23,33,39] In addition, the locking screws' orientation toward the humeral head with these nails has been the cause of intra-articular screw penetration with secondary glenoid erosion in cases of humeral head necrosis, similar to what has been observed with locking plates.[16,42,53,58]

In an effort to overcome these problems, we developed a third-generation humeral IMN (Aequalis; Tornier-Wright, Bloomington, MN, USA). This cannulated nail is short, has a small diameter, has a straight design (to enter the muscular portion of the supraspinatus), and uses locking screw technology with orientation of the screws for tuberosity fixation.[3,4] The aims of this study were (1) to classify displaced surgical neck fractures to determine the optimal entry points for percutaneous IM nailing and (2) to report the functional and radiologic results of this third-generation nail for the treatment of displaced 2-part surgical neck fractures using a percutaneous technique for nail insertion. We hypothesized that (1) the entry point for percutaneous insertion of an IMN would depend on the displacement of the humeral head fragment and (2) percutaneous fixation of displaced surgical neck fractures with a third-generation IMN would provide a high rate of fracture healing, excellent clinical outcomes, and a low rate of complications.

Methods

Study design

We performed a single-center retrospective study of patients with a 2-part displaced surgical neck fracture (AO/OTA type 11A3) treated with percutaneous insertion of a third-generation IMN. The inclusion criteria were (1) a displaced surgical neck fracture with displacement of the shaft of more than 25% of its width and/or more than 45° of angulation, (2) surgical treatment with the Aequalis IMN inserted percutaneously within the first 3 weeks after injury, and (3) clinical and radiologic review of patients with a minimum of 1 year of follow-up. We excluded patients with 3- or 4-part fractures, diaphysis fracture extension, concomitant fractures in the same upper limb, previous shoulder surgery, and pathologic or open fractures. All patients provided informed consent for participation.

Third-generation humeral IMN design rationale

The Aequalis humeral IMN is a third-generation IMN (Fig. 1) and was used in all cases in this series. The small (9-mm) core diameter, the low profile of its tip, and its cannulated design facilitate the percutaneous approach. The short length avoids premature distal locking, which has been shown to be associated with fracture site distraction and secondary nonunion.[3,9] The straight design allows for passage through the supraspinatus muscle fibers to avoid the tendinous insertion at the supraspinatus footprint. The straight nail

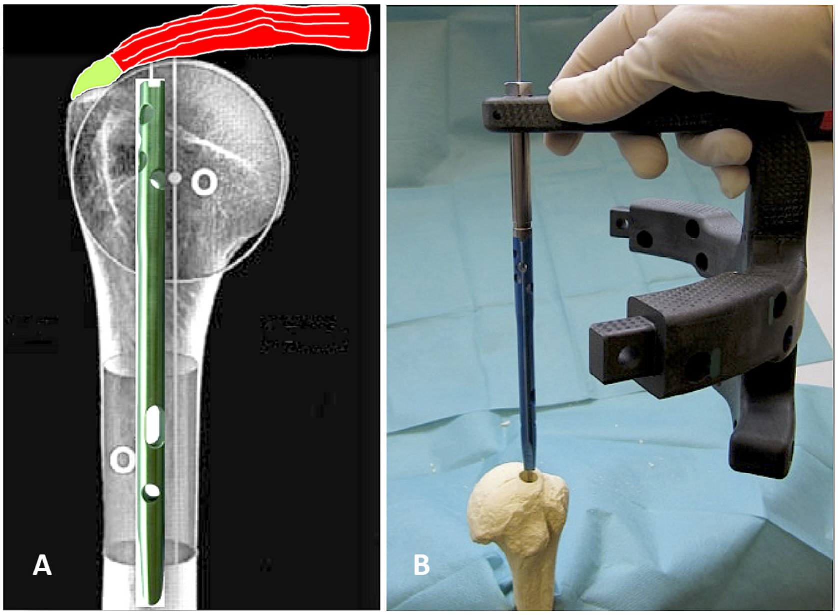

Figure 1 (**A**) Entry point of straight, locked (third-generation) intramedullary humeral nail (Aequalis). The straight design allows entry into the muscular part of the supraspinatus (not the tendinous part), while respecting the 3-dimensional geometry of the proximal humerus with alignment along the diaphyseal axis (diaphyseal cylinder). (**B**) The intramedullary nail, which is cannulated, enters through the cartilage, approximately 10 mm posterior and medial to the bicipital groove. Because of tuberosity-based fixation, there are 2 different nails: a green nail for the right side and a blue nail for the left side.

respects the 3-dimensional geometry of the proximal humerus, acting as a mechanical strut to support the humeral head under compressive forces.[3-5,7,54] The proximal locking screws are captured by a polyethylene bushing, which provides an angular-stable construct preventing screw back out and migration.[9] The proximal screws are tuberosity oriented (ie, not humeral head oriented) to avoid glenoid erosion in case of humeral head avascular necrosis and collapse. Finally, the 2 distal screws are 20° divergent to center the nail inside the medullary canal, increasing the construct's stability.[3,5,9]

Percutaneous IM nailing of 2-part surgical neck fractures

The surgical procedures were performed by 4 different senior surgeons. Patients were placed in the sitting (beach-chair) position and underwent surgery under general anesthesia in addition to an interscalene block. The arm was placed in a mobile arm support (Spider Limb Positioner; Smith & Nephew, Andover, MA, USA) with C-arm image intensifier control, approaching from the contralateral side of the table, to visualize the proximal humerus in the orthogonal planes. The goal of the minimally invasive percutaneous technique is to enter the cartilage of the humeral head (entering the supraspinatus muscle fibers, not the tendon) before entering the medullary canal of the diaphysis to align the head fragment and the shaft and, subsequently, to derotate the diaphysis (Fig. 2).

Under C-arm guidance, optimizing the starting point of the nail in the humeral head was essential to obtain anatomic reduction.[46] The entry point of a straight nail must be located approximately 10 mm posterior and medial to the bicipital groove.[14,26,29,38,42] Once the proper entry portal was defined, a cannulated bone awl was used for entry and to reduce the humeral head under fluoroscopic guidance. A guidewire was placed through the bone awl into the humeral head. After manipulation of the arm to obtain the best alignment between the epiphysis and diaphysis, the guidewire was advanced inside the humeral shaft.

Once adequate guide pin placement was achieved, a 9-mm hole was created in the humeral head using a cannulated reamer. The cannulated nail was placed over the guidewire and inserted at the apex of the humeral head and then inside the diaphysis, providing appropriate fracture alignment. The arm was placed in neutral rotation to achieve adequate derotation of the humeral diaphysis, whereas adequate rotation of the nail was achieved with the assistance of an external jig aligned with the forearm (Fig. 3).

After assessment of the reduction and the nail's depth under fluoroscopy, the guidewire was retrieved and the 2 distal screws were first placed in the diaphysis. Once distal fixation was obtained, gentle retrograde impaction of the distal to proximal segment via a sliding slap hammer was performed ("back-slap" hammering) to allow intraoperative immediate compression of the fracture site (Fig. 4). Finally, proximal fixation was obtained by percutaneous insertion of a minimum of 2 proximal locking screws via the attached jig.

Postoperative care

Patients were discharged the same day as or 24 hours after surgery. The shoulder was placed in a sling for 2 to 4 weeks postoperatively. Passive elbow and shoulder mobilization with pendulum exercises (5 times a day, 5 minutes per session) was performed immediately. Patients were encouraged to remove their sling often to perform light activities of daily living. After 2 weeks, formal rehabilitation with a physiotherapist was encouraged. Light strengthening was allowed at 6 weeks, with activity as tolerated allowed at 3 months postoperatively.

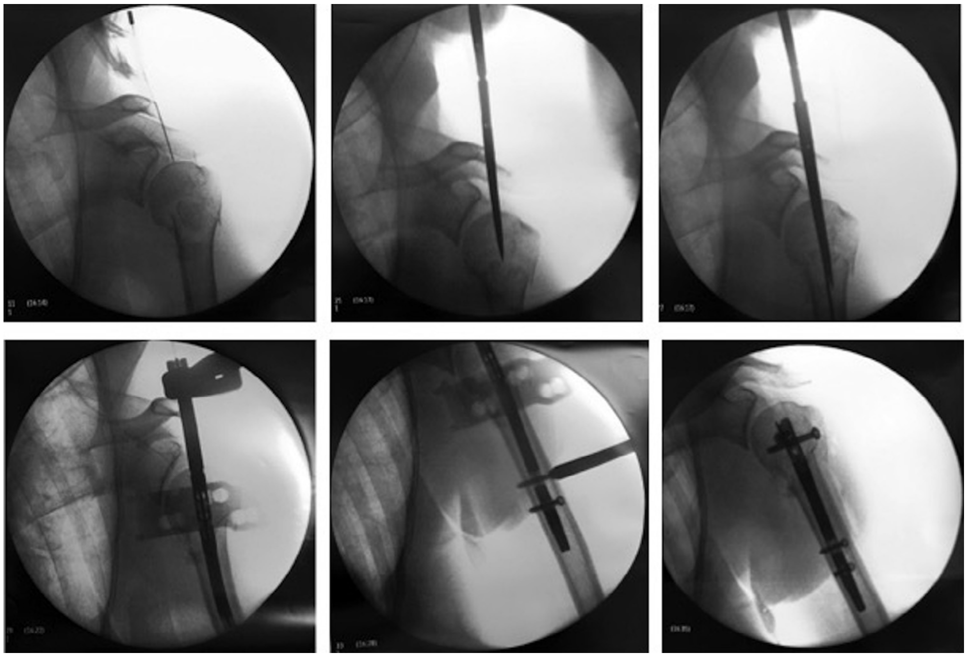

Figure 2 Percutaneous intramedullary nailing of 2-part surgical neck fracture. The goal is to enter the cartilage of the humeral head segment (and not the greater tuberosity) before entering the medullary canal of the shaft. After the location of the entry point is determined under fluoroscopy with a spinal needle, a cannulated awl is used to perforate the cartilage and manipulate the head fragment to allow for the passage of the guidewire in the diaphysis; the cannulated nail is then inserted along the guidewire. After fluoroscopic control of the humeral nail height, the diaphysis is derotated by aligning the jig on the forearm. Distal locking is performed first, and the back-slap technique allows immediate fracture compression before proximal locking.

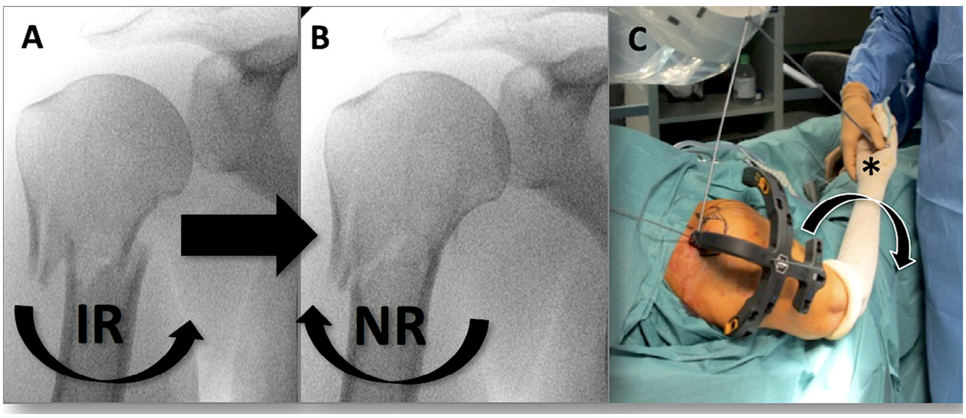

Figure 3 Closed reduction of 2-part displaced surgical neck fracture by derotation of diaphysis. (**A**) Before reduction, the diaphysis is displaced in adduction, translation, and internal rotation (*IR*) by pulling the thoracic muscles (pectoralis major, latissimus dorsi, and teres major). (**B**) Placing the arm in neutral rotation (*NR*) allows derotation of the diaphysis and almost complete fracture alignment. (**C**) Once the nail has been inserted percutaneously inside the humerus, the version rod is aligned with the forearm (*) to control the nail rotation.

Clinical outcome assessment

Clinical and radiographic evaluation occurred at 6 weeks postoperatively; 3, 6, and 12 months; and then yearly. Shoulder pain was assessed to establish entry-point morbidity. Shoulder function was assessed with absolute and sex- and age-adjusted Constant-Murley scores.[10] Patient satisfaction was assessed with the Subjective Shoulder Value.[19] The mean follow-up period was 26 months (range, 12-53 months).

Radiologic outcome assessment

On preoperative and postoperative anteroposterior and lateral (Y) views, translation between the epiphysis and diaphysis was assessed. The neck-shaft angle was measured on anteroposterior radiographs with the shoulder in neutral rotation, according to the method of Zhu et al.[57] The radiographs were evaluated for osteonecrosis of the humeral head, nonunion or malunion of the fracture, failure of fixation, and screw back out or cutout.

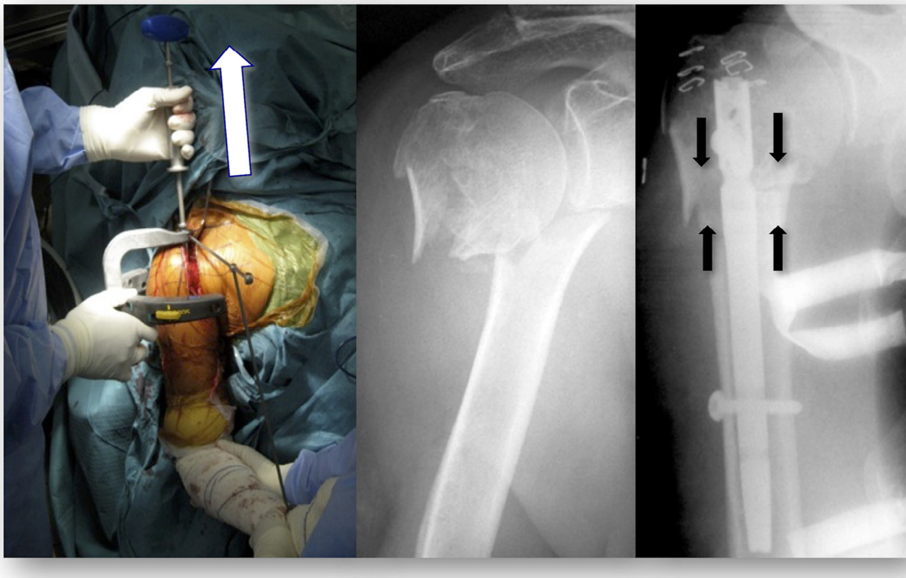

Figure 4 The back-slap hammering technique allows immediate fracture site compression. After fracture alignment and diaphysis derotation, distal locking of the intramedullary nail is performed first, followed by intraoperative retrograde hammering and then proximal locking.

Statistical analysis

Clinical results were evaluated in terms of age, pattern of displacement, and rate of reoperation. We calculated means and standard deviations for numeric outcomes and percentages for discrete outcomes. Comparison of numeric outcomes between groups of patients was performed with the Mann-Whitney *U* test for 2 samples and the Kruskal-Wallis *H* test for more than 2 samples. Data were analyzed with EasyMedStat (Neuilly-Sur-Seine, France; www.easymedstat.com). The level of significance was set at .05 ($P \leq .05$).

Results

Demographic characteristics

Between 2008 and 2013, 45 patients underwent treatment of displaced 2-part surgical neck proximal humeral fractures with straight, third-generation IMNs and fulfilled our study criteria with a minimum follow-up period of 12 months postoperatively. Of the 45 operatively treated patients, 4 did not have adequate follow-up or could not participate in the study. The mean age at surgery was 57 years (range, 17-84 years). There were 25 female and 16 male patients. The mechanism of injury was a low-energy trauma (fall) in 78% of cases (32 patients). The dominant side was involved in 55% of cases. The mean operative time was 42 minutes (range, 20-110 minutes).

Classification of displaced 2-part surgical neck fractures

By use of preoperative radiographs and computed tomography scans, surgical neck fractures were classified into 3 types, according to the displacement of the humeral head fragment (Fig. 5):

- Valgus surgical neck fractures (type A, 8 cases): The medial translation of the diaphysis is partial and combined with some abduction and rotation, which leads to valgus deformity of the humeral head.
- Translated surgical neck fractures (type B, 19 cases): When the shaft is entirely translated medially and anteriorly by the pectoralis major and internally rotated by the latissimus dorsi and teres major, there is no more contact between the head fragment and the diaphysis and, therefore, no humeral head deformity.
- Varus surgical neck fractures (type C, 14 cases): The shaft is translated laterally with some adduction and rotation, leading to varus head deformity.

With increasing surgical experience, we have used this classification to choose the optimal percutaneous entry point for the IMN (Fig. 6).

Complications and reoperations

At the final follow-up, 1 patient had partial avascular necrosis of the humeral head, which remained asymptomatic at the last review, 3 years postoperatively. With the proximal screws being tuberosity oriented, no screw penetration or glenoid erosion was observed.

At the final follow-up, 2 patients (5%) had undergone reoperation. One patient underwent reoperation for nail removal because of rotator cuff irritation, impingement, and shoulder pain. The nail was too proud, as seen on the immediate

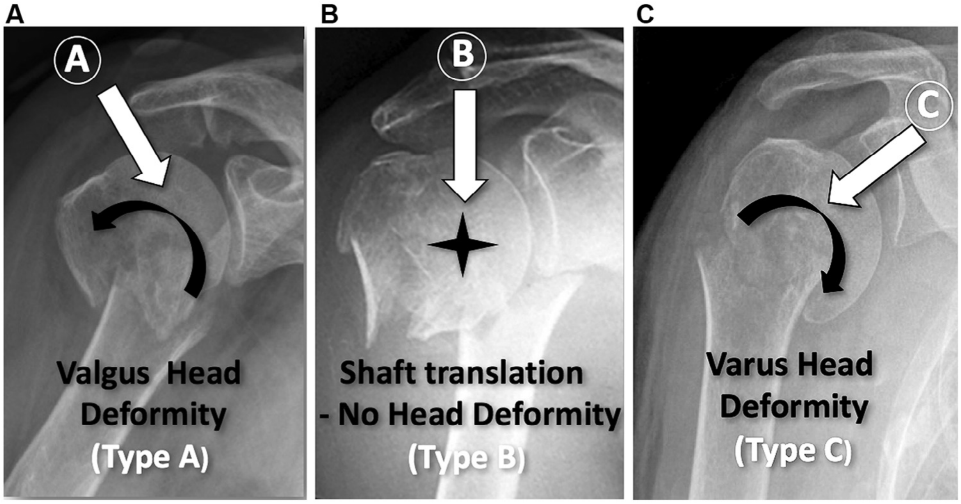

Figure 5 Surgical classification of displaced surgical neck fractures and relationship with nail entry point. Three types of surgical neck fractures have been identified. (**A**) Valgus head deformity (type A): partial shaft translation and abduction of the diaphysis lead to valgus tilt of the humeral head. (**B**) Shaft translation with no head deformity (type B): because of the complete shaft translation and the absence of contact between the 2 bone segments, the head is not tilted. (**C**) Varus head deformity (type C): partial shaft translation and adduction of the diaphysis lead to varus tilt of the humeral head. The *white arrows* are materializing the intramedullary nail entry point (*A, B, C*), which must be individualized according to the humeral head displacement: the more valgus, the more lateral; the more varus, the more medial.

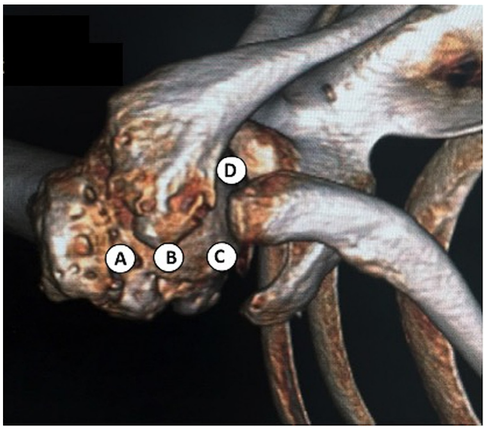

Figure 6 Three-dimensional computed tomography image showing different entry portals used to insert straight intramedullary nail. Portal A is used in the case of valgus deformity of the humeral head, portal B is used in the absence of head deformity with shaft translation, and portals C and D are used in the case of varus deformity of the humeral head. Portal D (Neviaser portal) is used in the case of combined varus and posterior tilt of the humeral head.

postoperative radiographs. This was attributable to intraoperative technical error with initial high placement of the nail because of oblique orientation of the C-arm. The other patient underwent arthroscopic scar release and removal of the anterior proximal screw because of postoperative stiffness despite prolonged rehabilitation. Owing to malrotation of the nail, the screw was inserted in the bicipital groove instead of the lesser tuberosity, and this was thought to be a cause of biceps irritation. The shoulder function in both patients improved after reoperation.

Table I Functional outcomes and active range of motion at last follow-up

	Mean ± standard deviation
Constant-Murley score	
Pain (maximum, 15 points)	13.6 ± 2.1
Activity (maximum, 20 points)	16.3 ± 2.6
Mobility (maximum, 40 points)	29.8 ± 7.5
Strength (maximum, 25 points)	8.7 ± 3.7
Total (maximum, 100 points)	68.4 ± 13.0
Adjusted Constant-Murley score, %	83.6 ± 11.6
Active range of motion	
Forward elevation, °	146 ± 24.0
External rotation, °	49.4 ± 19.0
Internal rotation on 10 points	6.2 ± 2.0 (L3)

Functional results

The functional results and active mobility at last follow-up are summarized in Table I. At last follow-up, the strength of the supraspinatus muscle on the affected side, tested with a dynamometer, was 4.9 ± 2.2 kg. The only patient who complained about cuff pain was the aforementioned patient with the proud nail who underwent reoperation for nail removal. At last follow-up, the mean Subjective Shoulder Value was 80% ± 12% (Fig. 7).

Radiologic results

Union of the fracture site was achieved by 3 months in all patients. No cases of screw back out or migration,

Figure 7 Radiologic, functional, and esthetic results after percutaneous intramedullary locked nailing and back-slap technique performed to treat a high-energy varus-displaced surgical neck fracture in a young active patient (aged 18 years). Postoperative anteroposterior and axial views demonstrate healing and restoration of the proximal humeral anatomy, with functional results and a cosmetic shoulder aspect 3 months after surgery.

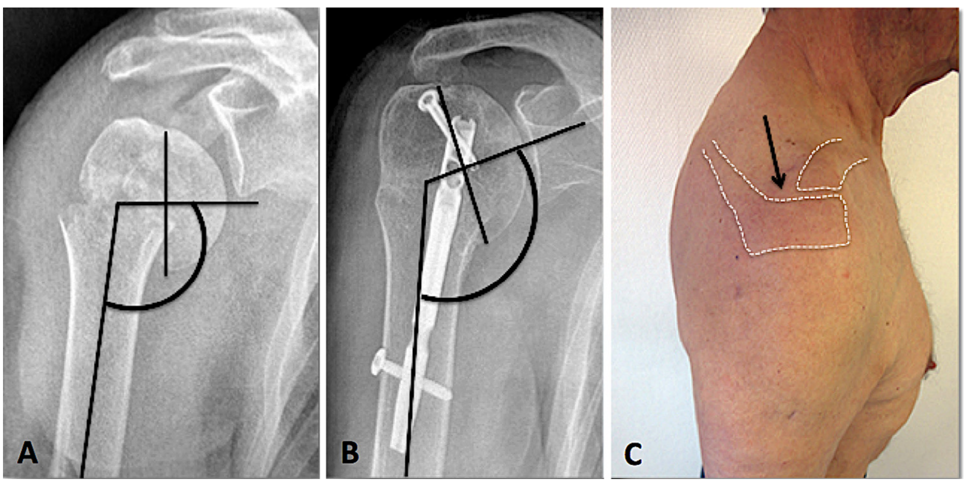

Figure 8 Correction of varus-displaced fracture using Neviaser portal for intramedullary nail insertion. (**A, B**) The preoperative humeral inclination is 95°, whereas the postoperative inclination measures 125°. (**C**) The Neviaser portal is defined by the clavicle anteriorly, the spine of the scapula posteriorly, and the medial border of the acromion. The nail enters the trapezius muscle and then the supraspinatus muscle. This portal is useful to correct a severe varus tilt associated with some posterior tilt of the humeral fragment.

intra-articular penetration, or loss of reduction were observed. The mean humeral neck-shaft angle at final follow-up was 132° ± 5° (Fig. 8). The mean correction of the angulation was 16.5° ± 8.3° (Table II).

A malunion was observed in 2 cases, early in our experience: One patient had incomplete reduction of humeral translation, whereas a varus malunion of the surgical neck developed in the other patient. Both fractures were noted to

Table II Correction of fracture displacement

Initial fracture displacement	Preoperative	Last follow-up	Final malunion
Valgus deformity (type A, n = 8), °	150(141-156)	135(120-139)	Residual valgus, n = 0
Shaft translation* (type B, n = 19), %	75 (30-100)	8 (0-50)	Residual translation, n = 1
Varus deformity (type C, n = 14), °	112(91-120)	130 (120-135)	Residual varus, n = 1

Data are presented as mean (range) unless otherwise indicated.
* Translation refers to the diameter of the surgical neck.

Table III Influence of initial fracture displacement on outcomes and reoperation

Fracture displacement	No. of cases	Mean age at surgery, yr	Adjusted Constant-Murley score, %	SSV, %	Reoperation, n
Valgus deformity (type A)	8	70 (63-81)	83 (65-110)	77 (60-90)	0
Shaft translation (type B)	19	61 (21-83)	84 (66-100)	79(50-100)	1
Varus deformity (type C)	14	44 (17-76)	83 (61-104)	82(50-100)	1
P value		.01	>.05	>.05	

SSV, Subjective Shoulder Value.
Data are presented as mean (range) unless otherwise indicated.

be malreduced at the time of surgery because of intraoperative technical error: The entry point of the nail was incorrect (ie, too lateral). With increasing surgical experience, we developed a strategy to achieve entry of the nail at the correct spot, based on the type of displacement of the humeral head fragment (Figs. 5 and 6).

Results according to initial fracture displacement

Regardless of the initial fracture displacement, the results were similar (Table III).

Results according to patient age

Considering age 60 years as a threshold, we identified 2 groups of patients (Table IV). Regardless of the initial fracture displacement, patients younger than 60 years had statistically better subjective and functional outcomes at the final follow-up.

Discussion

Most surgeons are reluctant to use antegrade IM nailing for the treatment of displaced 2-part surgical neck fractures of the proximal humerus and still prefer to use locking plate and screw fixation, although many complications related to this option have been reported throughout the literature.[2,27] For many surgeons, substantial barriers to adoption of antegrade IM nailing are the reported high rates of unexpected hardware complications (up to 50%) and unplanned reoperations (up to 16%) with first- and second-generation humeral nails. With the goal to avoid opening and plating these displaced surgical neck fractures and avoid or minimize complications reported with existing IMNs, we have designed a third-generation (straight design, locked, low-profile, tuberosity-based fixation) humeral IMN. The main objective of this study was to report the functional and radiologic results of this third-generation nail for the treatment of displaced 2-part surgical neck fractures using a percutaneous technique for nail insertion.

Table IV Influence of patient age on outcome

	Group 1: age > 60 yr (n = 23; mean age, 72 yr [range, 62-84 yr]; 8 male and 15 female patients)	Group 2: age ≤ 60 y (n = 18; mean age, 38 yr [range, 17-57 yr]; 9 male and 9 female patients)	*P* value
Pain score (out of 10)	1.3 (0-5)	0.5 (0-3)	>.05
Constant-Murley score	62 (43-87)	75 (61-95)	<.05
Active forward elevation, °	135 (90-170)	159 (120-180)	<.01
Active external rotation, °	38 (20-60)	61 (30-80)	<.01
Active internal rotation	5.4 (2-8)	7.1 (4-10)	<.05
SSV, %	74 (50-80)	86 (70-100)	<.05

SSV, Subjective Shoulder Value.
Data are presented as mean (range).

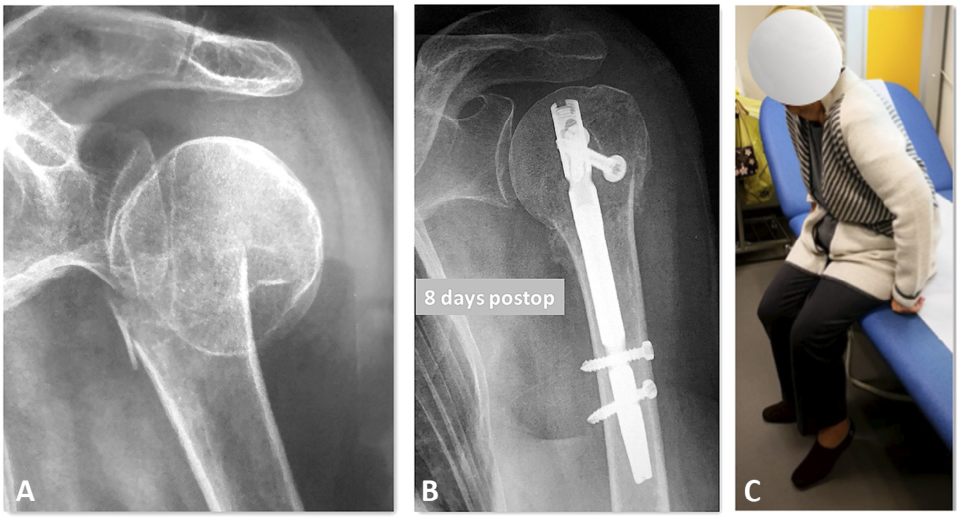

Figure 9 (**A-C**) The solidity of the construct given by the third-generation intramedullary locking humeral nail is demonstrated in a 91-year-old patient who is able, 8 days after surgery (*postop*), to push up spontaneously, without any pain, on her left operated upper limb to stand up from the table.

The results of this study show that insertion of such third-generation IMNs with a percutaneous technique provides a high rate of fracture healing and excellent clinical outcome scores, with a low rate of complications. We found several advantages of using this new generation of humeral IMNs through a percutaneous approach for the treatment of displaced 2-part surgical neck fractures, including minimal soft-tissue damage with minimal risk of humeral head osteonecrosis (only 1 case in our series), a short operative time (42 minutes on average, including our learning curve), and improved cosmesis (Fig. 8).

Although the first generation (unlocked) of humeral IMNs had a straight design, some of the problems encountered with these implants were related to their large diameter and excessive length, as well as the absence of efficient mechanical locking for the proximal screws.[14] Because most of these nails were too large and too long, distal nail engagement with the humeral canal could occur before the fracture had completely healed, leading to surgical neck nonunion.[3,4,23] No case of surgical neck nonunion was seen in our patients, possibly owing to the small diameter of our nail (9 mm), its short length (13 cm), and the low profile of its distal tip. Another major disadvantage of the first generation of humeral nails was inadequate security of the proximal screws leading to hardware problems, loss of reduction, and the need for unexpected reoperations.[14] Our results show that, even in elderly patients with osteoporosis and suboptimal bone density, locking technology applied to the humeral nail is reliable, providing strong capture of the proximal screws and avoiding hardware problems (Fig. 9).[3,4,9] No cases in our series showed screw migration or loss of reduction, thanks to the polyethylene bushing located inside the proximal part of the nail, which allows efficient locking of the proximal screws.[9]

The use of curved design second-generation humeral IMNs has been associated with even poorer results and high rates of complications and reoperations.[33,39] Nolan et al[39] reported that more than 50% of patients operated on with a second-generation (curved design) antegrade IMN had rotator cuff disease. Lópiz et al,[33] comparing straight and bent nails, showed that postoperative symptoms related to rotator cuff irritation or tears were present in 73% of the bent-nail group compared with 35% of the straight-nail group; reoperation was performed in 42% of the patients in the bent-nail group and 11.5% in the straight-nail group. The problem with these second-generation (curved design) humeral IMNs is that either the IMN is inserted laterally (through the supraspinatus footprint), creating an iatrogenic cuff tear, causing shoulder pain and stiffness, or it is inserted medially (through the humeral head), thus preventing anatomic fracture reduction and creating a surgical neck malunion.[3,5]

Preservation of cuff tendon integrity is of paramount importance when using antegrade IM nailing.[14,29,33] The straight design of the Aequalis humeral IMN offers the advantage of entering the supraspinatus through the muscle belly, instead of its tendinous insertion. Although we did not perform any imaging studies of the cuff, no clinically related consequences due to the passage of the nail through the supraspinatus muscle belly were observed in this study. On the basis of our surgical experience, it is our opinion that entering the cuff musculature with a small-diameter (9-mm) IMN is comparable with entering a similar-diameter (8-mm) cannula through the cuff muscles during shoulder arthroscopy, a practice that is commonly used and widely accepted.[14,29,34] Except for the 1 patient who underwent reoperation for removal of a prominent nail (initially inserted too proud), no patient in our series complained about shoulder pain.

As stated by Neer[36] many years ago, there is no humeral head fragment rotation in displaced 2-part surgical neck fractures, owing to the balanced force vectors of the anterior and posterior rotator cuff. Therefore, there is no need to derotate the epiphyseal segment; only valgus or varus of the head, when present, must be corrected. This can be done easily with a humeral IMN by entering the humeral head and then using the nail as a joystick to reduce the fracture. However, to enter the humeral head at the correct spot, surgeons should be aware of its potential displacement. Another pertinent finding of our study is the classification of displaced surgical neck fractures, which allows the determination of optimal entry points for percutaneous insertion of a straight humeral IMN. The surgical classification that we propose, based on the displacement of the humeral head fragment, is helpful to determine the optimal entry point of the IMN for percutaneous insertion (Figs. 5 and 6). We observed that, in the absence of humeral head displacement (type B, translated surgical neck fracture), the optimal entry portal is usually located just anterior to the acromion. For valgus head deformity fractures (type A, valgus surgical neck fracture), the entry portal must be located more laterally, whereas for varus displaced fractures (type C, varus surgical neck fracture), a more medial portal, anterior or posterior to the acromioclavicular joint, is appropriate. In the case of varus with additional posterior tilt of the humeral head fragment, the Neviaser portal[29,37] (located posterior to the acromioclavicular joint) may be useful; we used this portal in 5 cases in our series (Fig. 8).

Dynamic distal fixation has been proposed with first- and second-generation humeral nails.[23] As the upper limb is subjected to more distraction rather than compression forces (as found in the femur or tibia), for the humerus, we prefer to use a technique that allows immediate intraoperative axial fracture compression to maximize fracture stability and allow immediate activity and rehabilitation.[20,23] To safely perform the back-slap technique and avoid nail protrusion, surgeons should make sure that the patient is in the sitting position with the C-arm placed horizontally, strictly orthogonal to the humerus (to avoid any misjudgment in the nail height). The nail must be inserted 5 to 10 mm deep to the superior surface of the humeral head (to avoid secondary nail protrusion) before retrograde impaction.[14] Another option is to first proximally lock the nail and then put compression on the fracture site by impacting the elbow distally with the arm in neutral rotation.

The main limitation of our study is the absence of a control group that would have received the alternative, and more accepted, care method (ie, locking plate fixation). We did not believe it was ethical to propose open reduction and internal fixation to our patients when we had the possibility to perform a percutaneous treatment that allows closed reduction and equivalent strong fixation. We accept that, given the relatively short period of follow-up of our study, caution should be used when interpreting the long-term incidence of avascular necrosis and osteoarthritis in this cohort. In contrast to other studies that often evaluate the outcomes of heterogeneous fractures of the proximal humerus (mixing 2-, 3-, and 4-part fractures), we limited the inclusion criteria to a single type of fracture (2-part surgical neck fracture). This is a strength of our study, in addition to the use of the same technique and implant for all fractures. Moreover, patients were evaluated postoperatively with validated scoring systems to assess the functional and subjective results, and imaging studies were standardized to assess the quality of reduction and fracture healing.

Conclusion

In this series, antegrade insertion of a third-generation IMN through a percutaneous approach provided a high rate of fracture healing and excellent clinical outcome scores, with a low rate of complications. The straight design and small dimensions (in diameter and length) of the Aequalis IMN avoid the iatrogenic cuff problems seen in the past with first- and second-generation humeral nails. No morbidity related to the passage of the nail through the supraspinatus muscle and the head cartilage was observed. In our opinion, percutaneous IM nailing of displaced surgical neck fractures using a third-generation IMN provides the combined advantages of pinning (biological fixation with minimal dissection of the fracture site) and plating (biomechanically strong construct), without the drawbacks of both techniques.

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