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Proximal humeral fracture locking plate fixation with anatomic reduction, and a short-and-cemented-screws configuration, dramatically reduces the implant related failure rate in elderly patients

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A R T I C L E I N F O

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Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Background: Multiple studies have reported an unacceptable implant-related complication rate in proximal humeral fractures treated with locking plates, particularly in older patients. Our objective was to compare the fracture fixation failure rates in elderly patients, after a dedicated technique for locking plate fixation with cement augmentation or without it.

Methods: A total of 168 open reduction and internal fixation with locking plates were performed for complex proximal humerus fractures by a single surgeon in 136 women and 32 men older than 65 years of age (average 76 years). Treatment groups included group 1 with noncemented screws (n = 90) and group 2 with cemented screws (n = 78). As per Mayo-FJD Classification, there were 74 (44%) varus posteromedial impaction, 41 (24%) algus impaction, 46 (28%) surgical neck, and 7 (4%) head dislocation injuries. A retrospective radiographic and a clinical analysis was performed.

Results: At a mean follow-up of 33 months, the implant failure rate was significantly lower in the cement augmentation group (1% vs. 8%, $P = .03$). The overall complication rate was 21% (25% group 1, 15% group 2; $P = .1$). Global avascular necrosis was associated with sustaining a valgus impacted fracture ($P = .02$ odds ratio 5.7), but not to augmentation. Partial avascular necrosis occurred only in patients treated with cemented screws (3.8%). The overall revision rate was 9% in both groups. Forward elevation was 126 ± 36 degrees and external rotation was 44 ± 19 degrees. The mean Constant score was 70 ± 15 in group 1 and 76 ± 15 in group 2 ($P = .03$).

Conclusion: Cement augmentation significantly decreased the rate of implant failure. Good results are expected for most patients treated with this technique.

Despite the vast majority of proximal humerus fractures being treated nonoperatively, for displaced proximal humeral fractures, open reduction and internal fixation with locking plates has been the most frequent surgical treatment in the last two decades.[29] Nevertheless, it has been difficult to prove scientifically that surgery provides a better outcome than nonoperative treatment, not because nonoperative treatment leads to universally good results but because surgical management has been associated with an unacceptable rate of complications, including screw back-out, screw cut-out, screw intra-articular penetration, loss of reduction, malreduction, malunion, and nonunion.[3,5,6,17,20,22,23,25-28,30,31] These complications are more common in older patients with osteopenia, when fracture fixation with a locking plate relies on metal screws holding osteoporotic cancellous bone.[4,7,12,20] Intra-articular screw penetration is the most frequent complication reported and can be the result of (1) intraoperative insertion of excessively long screws violating the subchondral bone (primary screw penetration) or (2) fracture collapse with loss of reduction leading to late screw penetration owing to locked screws cannot back out (secondary screw penetration).

Efforts have been made to strengthen the fixation of locking plates and make the repairs more resilient to fracture fixation loss, head collapse, and secondary screw penetration. In vitro biomechanical studies have demonstrated enhanced primary stability of

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proximal humerus plating with acrylic PMMA bone cement augmentation of screw tips.[21,33] However, the clinical findings have been controversial regarding the benefit of bone cement augmentation with the proximal humerus internal locking system and only a single clinical study highlighted the improved primary stability seen with cement augmentation. These variable results may be related to heterogenicity in augmentation techniques, screw configurations and heterogenicity of fracture patterns.[11,14,16]

Our primary objective was to compare the rate of implant failure after locking plate fixation of complex PHF using cement augmentation of humeral head screws vs. plate fixation without cement. The secondary goal was to compare range of motion, functional outcomes, and the occurrence of additional complications between both groups. We hypothesized that implant failure may occur less frequently when osteosynthesis is performed with cemented screws, compared with those treated without cement augmentation.

Methods

Study cohort and data collection

Our institutional surgical coding office provided a list including 318 patients older than 65 years of age undergoing surgery for acute proximal humeral fracture between 2009 and 2019. Twelve were treated with osteosuture, 56 with reverse shoulder arthroplasty (RSA) (Delta Xtend; DePuy Synthes, Zuchwil, Switzerland), and 250 with open reduction and internal fixation with locked plating (PHILOS; DePuy Synthes, Zuchwil, Switzerland). A total of 190 plate osteosynthesis were performed by a single surgeon (AMF). The exclusion criteria were less than one year of follow-up (discarding 7 nonrelated deaths and 9 follow-up losses) and preoperatively diagnosed central or peripheral neurologic deficiency (distinct dementia, 3 patients; hemiparesis, 2 patients; and lesion of the axillary or other major peripheral nerves, 1 patient). There were no pathologic or open fractures. The resultant 168 cases form the basis of this retrospective comparative cohort study. Cement augmentation for locking plates (Trauma Cem Vþ; DePuy Synthes) was commercially available in March 2014 and was routinely implemented after that date. Patients were divided into two different treatment groups: group 1 with noncemented screws (n = 90) and group 2 with screw cement augmentation (n = 78).

Fracture classification

Fractures were classified as per Neer (Table I) and Mayo/FJD Classification (Table II). Mayo/FJD Classification contemplates seven common fracture patterns (Fig. 1): isolated fractures of the greater or lesser tuberosity (**GT, LT**), fractures of the surgical neck (**SN**) with or without metaphyseal extension, fractures at the anatomic neck level with head displacement in varus and posteromedially (**VPM**) or in valgus (**VL**), and fractures where the head is dislocated (head dislocation, **HD**), split (head splitting, **HS**) or depressed (head impaction, **HI**). Fractures of one or both tuberosities may or may not be present in the SN, VPM, VL, HD, HS, and HI patterns. This classification correlates fracture pattern and displacement with outcomes when fractures are treated conservatively.[8,9]

However, not all these patterns are included in this study because we treat isolated tuberosity fractures with osteosutures when displaced, while HS and HI fractures are considered most frequently for RSA. As per that, there were 74 (44%) varus posteromedial impaction, 41 (24.5%) valgus impaction, 46 (27.4%) surgical neck, and 7 (4.2%) Head Dislocation (Table II, Fig. 1).

Table 1
Comparison of fracture classification as per neer system for each treatment group ($P = .53$).

$P = .53$	Noncemented, group 1 (n = 90)	Cemented, group 2 (n = 78)	Total (168)
2-part surgical neck n (%)	13 (14.4)	12 (15.4)	25 (14.9)
3-part GT n (%)	48 (53.3)	26 (33.3)	74 (44)
4-part n (%)	13 (14.4)	32 (41)	45 (26.8)
Fx-disloc (%)	5 (5.6)	1 (1.3)	6 (3.7)
Head split n (%)	1 (1.1)	-	1 (0.6)
Nonclassifiable n (%)	10 (11.1)	7 (9)	17 (10)
Total	90 (100)	78 (100)	168 (100)

Ant, anterior; *GT*, greater tuberosity; *Fx-Disloc*, fracture dislocation; *Pos*, posterior.

Table 2
Comparison of Mayo/FJD classification fracture patterns for each treatment group ($P = .16$).

$P = .16$	Noncemented, group 1 (n = 90)	Cemented, group 2 (n = 78)	Total (N = 168)
VPM n (%)	37 (41)	37 (47.4)	74 (44)
VL n (%)	26 (28.9)	15 (19.2)	41 (24.5)
SN n (%)	21 (23.3)	25 (32.1)	46 (27.4)
HD n (%)	6 (6.7)	1 (1.3)	7 (4.2)

VL, valgus impaction; *GT*, greater tuberosity; *LT*, lesser tuberosity; *SN*, surgical neck, *HD*, Fracture with associated head dislocation.
No differences in.

Surgical procedure

Surgery was performed with the patient in the beach-chair position, with an interscalene block and either light sedation, or general anesthesia depending both on patient comorbidities and collaboration. Every patient received prophylactic intravenous antibiotics as a preoperative dose (cephazolin, 2 grams).

Surgical technique principles are as follows (Fig. 2)[9]:

1 Provisional anatomic reduction before definitive fixation
2 Axial placement of the plate with reference to the humeral head
3 Maximize the number of screws engaging the head segment
4 The use of a short screw configuration to avoid intra-articular screw penetration even if fracture settling happens.
5 Selective screw acrylic cement augmentation (only in Group-2).

Surgery steps are as follows:

1 A modified deltopectoral approach with a lateralized and vertical skin incision
2 Traction sutures placement through the rotator cuff
3 Anatomic head reduction and provisional fixation with 1.6-mm threaded wires introduced trough the rotator interval toward the diaphysis.
4 Anatomic tuberosity reduction and fixation with subscapularis to infraspinatus cerclage-like cuff sutures.
5 Definitive plate and short screw fracture fixation (see below).

Fracture fixation was achieved by a proximal humeral interlocking plate system (PHILOS; DePuy Synthes, Zuchwil, Switzerland). The plate was placed flat on the lateral side of the humerus, over the greater tuberosity, and axially oriented so the screws can get purchase in the head in multiple points. Only locking screws were used for head fixation. Only the proximal cortical was perforated with the drill. A manual measurer was introduced trough the drilled hole deep into the cancellous bone, in the direction of the screw, until hard subchondral bone is felt. A short

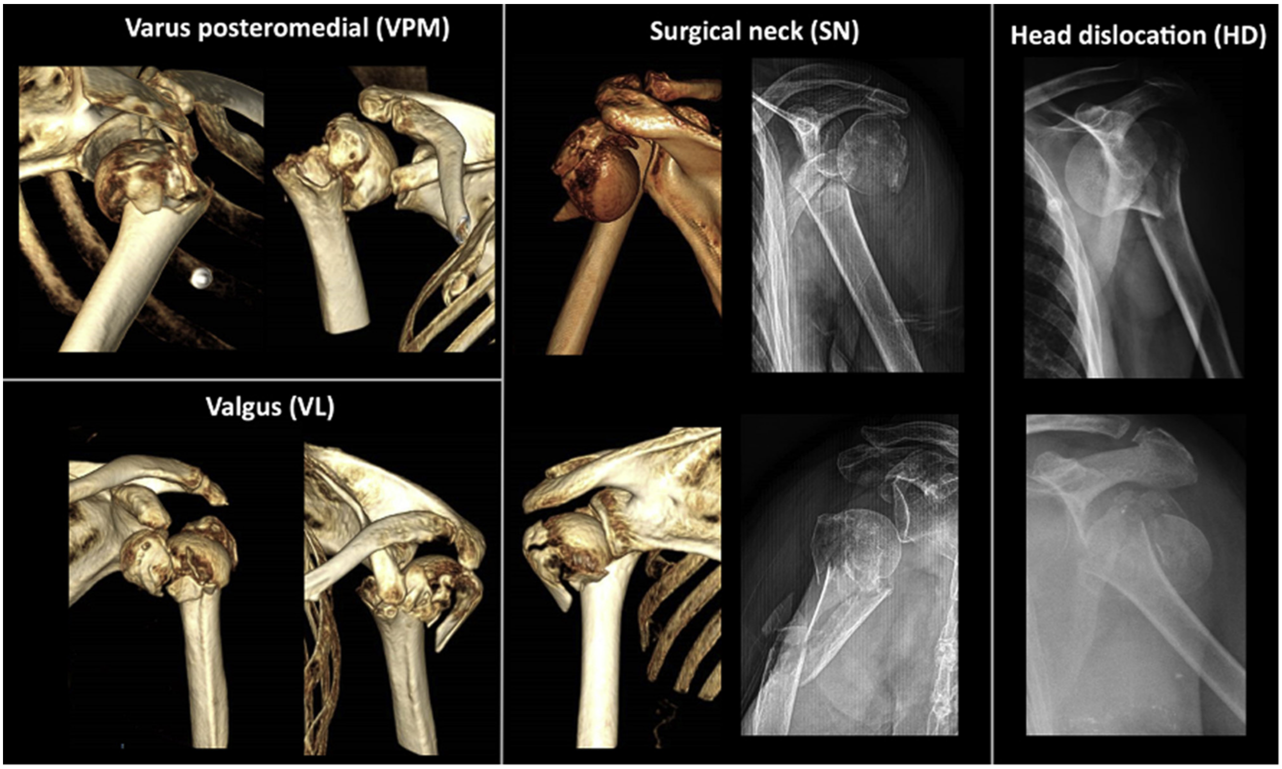


Figure 1 Examples of fractures included in our study, classified with Mayo-FJD System.

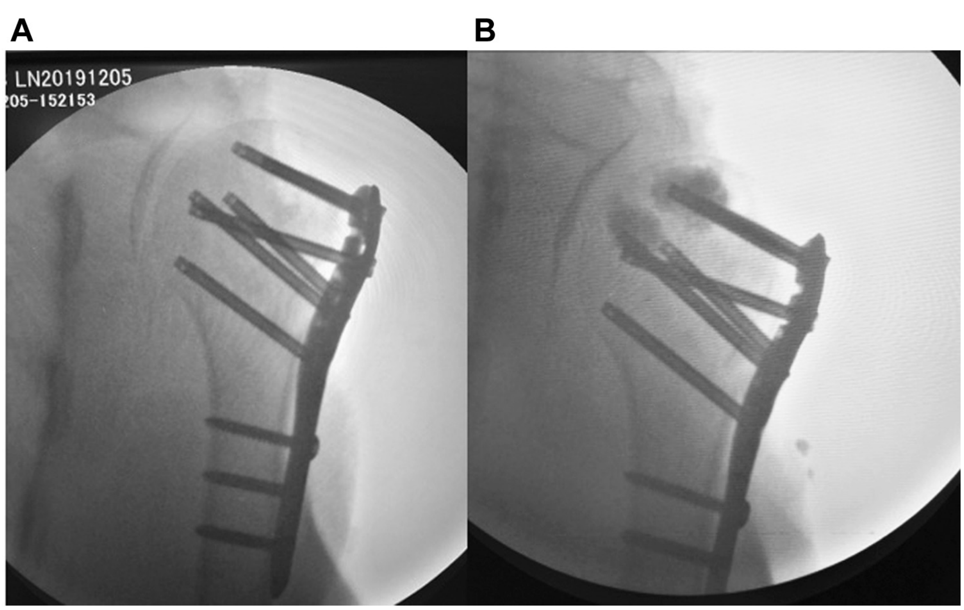


Figure 2 Final radioscopy after fixation (A), and after cement augmentation (B), illustrating the principles of proximal humeral fracture locking plate fixation (see text for details).

screw length selection was done; we subtracted 4 mm from the measured screw dimension when solid, noncemented screws were selected (group 1), and we subtracted 6 mm when cannulated screws for cement augmentation were chosen (group 2). Additional screw lesser tuberosity fixation was implemented when judged necessary. When screw-tip augmentation was performed, a commercially available system (Trauma Cem Vþ; DePuy Synthes) was used, providing a low viscosity, low temperature, and slow-curing acrylic cement that is introduced through specific cannulated locking screws. An average of 4.8 cannulated screws (range 3-7) was augmented with 0.4 to 0.6 cc of cement. The whole procedure was performed under fluoroscopic control.

Rehabilitation protocol

A commercial shoulder immobilizer was used for 6 weeks. Active range of motion exercises of the elbow, wrist, and hand were encouraged immediately. Codman forward flexion exercises were

Table 3
Comparison of patient demographics, surgical details, and follow-up between groups.

Variable	Noncemented, group 1 (n = 90)	Cemented, group 2 (n = 78)	P value
Age (yr) (mean ± SD)	76 ± 6	76 ± 8	.9
Female gender n (%)	71 (79)	65 (83)	.3
Dominant side fractured n (%)	52 (58)	34 (53)	.3
Time to surgery – d – (mean ± SD)	8.9 ± 5	9.2 ± 12	.72
Surgical time – min – (mean ± SD)	95 ± 28	105 ± 27	.014
Follow-up mo (mean ± SD)	43 ± 30	24 ± 12	<.001

started the day after the surgery. Passive self-assisted exercises in elevation and external and internal rotation were implemented at week 2. Active assisted range of motion and progressive stretching started at week 6. Normal life activities involving the shoulder are encouraged after week 8, restricting carrying weights until week 12.

Follow-up and outcome measures

Medical records comprising demographic information, surgical time, surgical protocols, and radiographs were collected from our hospital electronic digital records database. The standardized follow-up comprised clinical and radiographic examinations of the affected shoulder after 6 weeks, at 3, 6, and 12 months, and every year since then. Range of motion (in degrees for elevation and external rotation, and spine level reached with the thumb for internal rotation) and age- and gender-corrected Constant scores[13] were also collected at the last follow-up by an independent investigator (NMC) not involved in the treatment of the patients, with a specific interview for this study when the patients were still alive. For the rest of the cases, clinical records where used to collect clinical information.

Radiographic evaluation

In all patients, anteroposterior and lateral Y-view radiographs were assessed after surgery and at every follow-up for radiographic complications, and whenever suspected, additional image tests were obtained (computed tomography scan or ultrasound). Implant failure was defined as the occurrence of any of the following: loss of reduction and fracture collapse (with or without secondary screw intra-articular penetration) or screw back-out (complete dissociation of the locking threads from the plate). Loss of reduction and fracture collapse was defined as a change in the humeral head-shaft angle of more than 20° compared with the intraoperative reduction assessed fluoroscopically.[15,19] Avascular necrosis was evaluated according to Hattrup and Cofield.[10] Cases in which necrosis appeared only around cemented screw tips were considered partial avascular necrosis.

Statistical evaluation

Statistical analysis was performed using SPSS software (IBM SPSS Statistics for Windows, version 24.0; IBM, Armonk, NY, USA). Demographic data and functional outcomes were described by means and standard deviations and were compared with an independent-samples t or ANOVA test, with Bonferroni post hoc test. Radiographic characteristics and all categorical variables were analyzed with the χ^2 test. The level of significance for all testings was set at $P < .05$.

Results

There were 136 women and 32 men with an average age of 76 ± 7 years (range 65 to 94 years). Table III shows general demographics of our sample. No statistically significant differences were found in Neer ($P = .53$) or Mayo-FJD ($P = .16$) classification distribution between treatment groups (Tables I and II).

Surgery was performed within a mean of 9 ± 8 days after the injury. The row of screws that was most commonly selected for augmentation was row A in 99% (77 fractures), followed by row D in 81% (63 fractures), row B in 79% (62 fractures), row E in 54% (42 fractures), and row C in only 36% of cases (28 fractures) (Fig. 3). The most common configuration used was cemented screws in rows A, B, D, and E, selected in 27% of cases (Fig. 4). The mean duration of surgery was 100 ± 29 minutes; screw tip augmentation increased the surgical time a mean of 10 minutes (95 ± 26 group 1, 105 ± 26 group 2, 95% confidence interval [CI] 2-19 $P = .014$). The mean follow-up was 33 ± 26 months. Twenty-seven (16, 23% group 1 and 8% group 2) patients died after surgery by nonrelated causes.

At the last follow-up, the rate of implant failure was significantly lower in the group 2 (cemented) – 1 case, 1% – than in the group 1 (without cement) – 8 cases, 9% – ($P = .03$, odds ratio 0.13, 95% CI 0.02-1.08). The overall complication rate was 21% (25% group 1, 15% group 2; $P = .1$) (Table IV). The most common complication in group 1 was implant failure (9%) with 8 cases of loss of reduction with or without screw penetration and 1 case of screw back-out and loss of fixation. The most common complication in group 2 was plate subacromial impingement with 4 cases (5%). Implant failure was detected in both groups within the first 3 months postoperatively (mean 1.3 months, range 0.7-2.5) and occurred in all fracture patterns: VPM 3 cases (4% of all VPM), SN 3 cases (6.5% of all SN), VL 2 cases (5% of all VL), and HD 1 case (14% of all HD).

The overall rate of global avascular necrosis was 4.8%, (5.6% group 1, 3.8% group 2, $P = .7$). The mean time to detection of global avascular necrosis was 8.1 months (range 4.6 to 12.1). Group 1 showed AVN 8.5 ± 3 months after surgery and group 2 11.7 ± 0.4 months after surgery ($P = .23$). The only factor associated with global avascular necrosis was sustaining a valgus impacted fracture pattern as per Mayo/FJD Classification ($P = .02$; odds ratio 5.7, 95% CI 1-25). A total of 5 of 41 (12%) valgus impacted fractures had a global avascular necrosis as opposed to 3 of 127 (2.4%) of occurrence in all the other fracture patterns together.

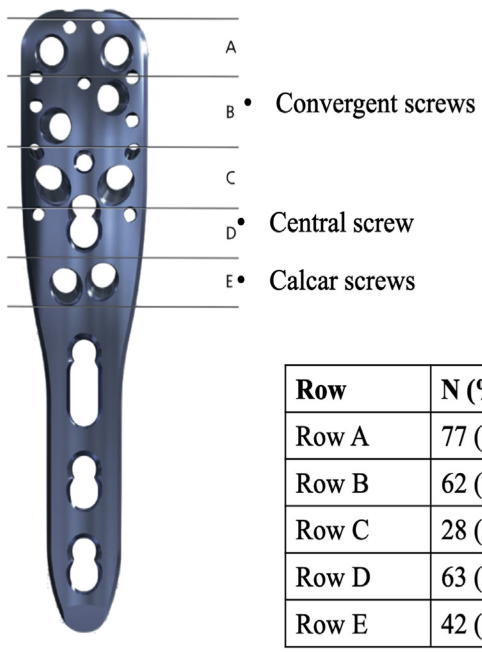
Partial avascular necrosis occurred only in patients treated with cement, with 3 of 78 (3.8%), and had no relation to fracture pattern ($P = .57$). The mean time to partial avascular necrosis was 11.6 months (range 10.8 to 11.2). Characteristically, partial avascular necrosis occurred in all cases around cemented screws in row A (Fig. 5).

We observed 9 (11.5%) cases of cement extrahumeral location, without any apparent effect in outcome in any of the cases, in group 2. All cement extravasations were seen in relation with calcar cemented screws in row E (Fig. 6).

Revision surgery

The overall rate of revision surgery was 9% without differences between both groups (Table V). In group 1, plate removal was performed in 2 cases of loss of fixation and fracture collapse, 1 case of global avascular necrosis, and 4 cases of plate subacromial impingement. One case of peri-implant fracture was treated with plate removal, close reduction, and intramedullary nail fixation, while the other two cases were treated conservatively.

In group 2, plate removal was performed in 4 cases of plate subacromial impingement and 1 case of global avascular necrosis, while conversion to RSA was necessary in 1 case of global avascular necrosis and 1 case of partial avascular necrosis. When revision surgery was necessary, we observed that removal of PMMA-augmented screws was technically easy, provided all screws heads had been cleared of cement during the index procedure.



Row	N (%)
Row A	77 (99%)
Row B	62 (79%)
Row C	28 (36%)
Row D	63 (81%)
Row E	42 (54%)

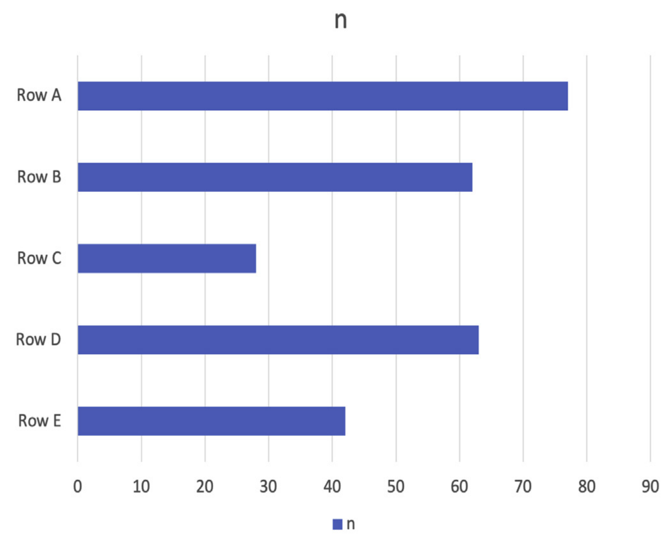


Figure 3 Frequencies of screw cement augmentation in patients include in group 2.

Row	N (%)
A,B	4 (5%)
A,B,C	1 (1%)
A,B,C,D	11 (14%)
A,B,C,D,E	7 (9%)
A,B,D	12 (15%)
A,B,D,E	21 (27%)
A,B,E	4 (5%)
A,C	3 (4%)
A,C,D	5 (6%)
A,C,E	1 (1%)
A,D,E	5 (6%)
A,E	3 (4%)
B,C,D,E	1 (1%)

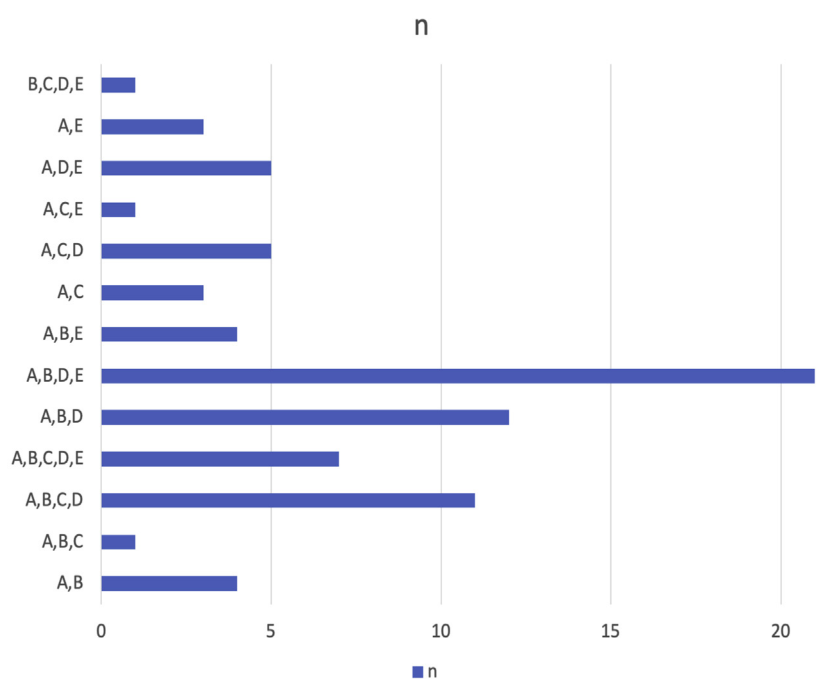


Figure 4 Frequencies in screw cement configurations in group 2.

Clinical outcome

At the latest follow-up, mean active forward elevation was 126 ± 36 degrees, mean active external rotation was 44 ± 18 degrees, and most common internal rotation to the area L2-T12 (range from greater trochanter to T4). Group 2 showed a means difference of 10 more degrees of external rotation compared with group1 (P = .001, 95% CI 4-15 degrees) and a means difference of 7 more points in the age- and gender-adjusted Constant score (P = .03, 95% CI 0.5-14; Table VI).

Discussion

The use screw-tip augmentation reduced the implant failure rate in displaced proximal humerus fractures treated with locking plates in elderly patients (from 8% to 1%). The findings reported in

Table 4
Complications occurred in the study groups.

	Noncemented, group 1 (n = 90)	Cemented, group 2 (n = 78)	Total (n = 168)
Patients with no complications (%)	67 (74)	66 (85)	133 (79)
Implant failure n (%)	8 (9)	1 (1.3)	9 (5.4)
Global avascular necrosis n (%)	5 (5.6)	3 (3.8)	8 (4.8)
Cement-related partial avascular necrosis n (%)	-	3 (3.8)	3 (1.8)
Primary intra-articular screw penetration n (%)	-	-	-
Plate subacromial impingement n (%)	5(6)	4 (5)	9 (5.4)
Peri-implant fracture n (%)	3 (3)	-	3 (1.8)
Pseudoparalysis with rotator cuff tear n (%)	-	1 (1.3)	1 (0.6)
Nonunion n (%)	1 (11)	-	1 (0.6)
Axillary neuropathy n (%)	1 (1)	-	1 (0.6)
Total patients with complications (%)	23 (25)	12 (15)	35 (21)

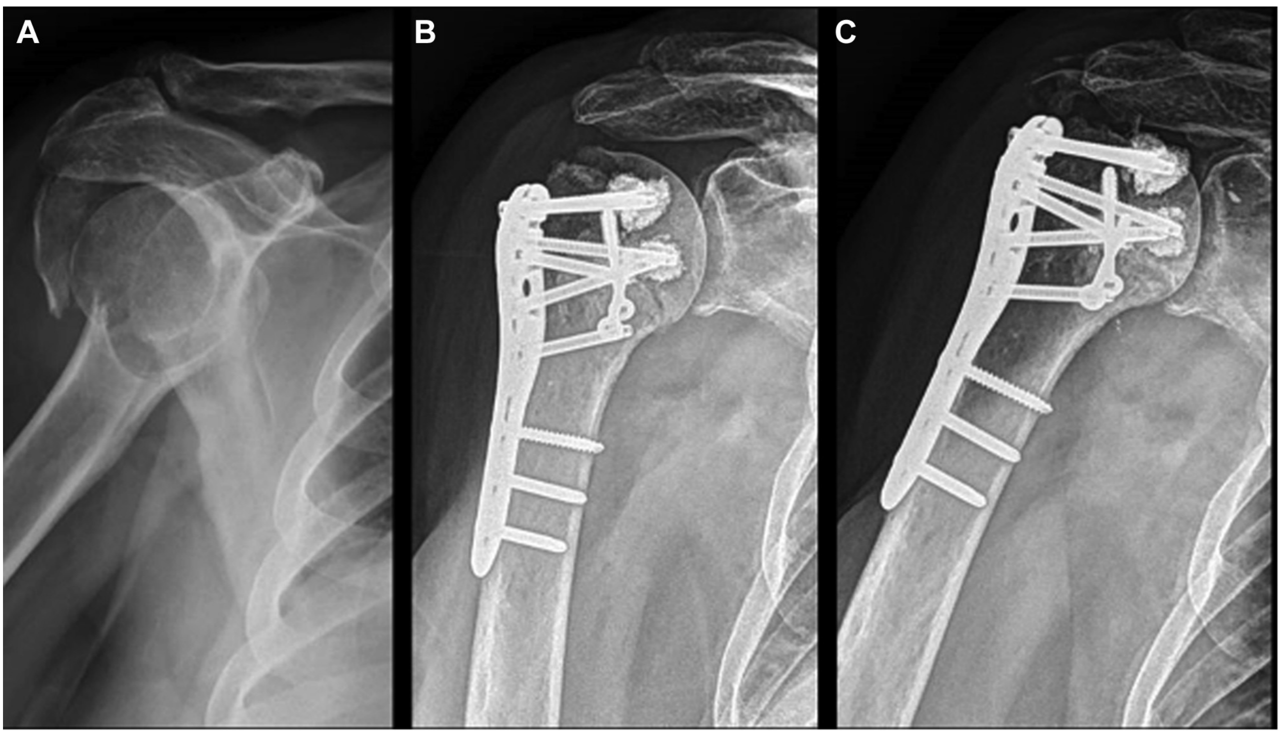


Figure 5 Partial avascular necrosis after ORIF with screw tip augmentation. (A) Preoperative x-ray. (B) Postoperative anteroposterior shoulder view. (C) Partial avascular necrosis proximally to the most cranial screws. ORIF, open reduction and internal fixation.

our series support the results of previous clinical studies. Katthagen et al[14] showed in a single-center prospective case-control study, a reduction in mechanical failure rate from 16.7% to no such complication in the cement-augmented group. However, augmentation did not affect Constant scores at three or twelve months. Siebenbürger et al,[24] in a retrospective study of 94 patients, reported no statistically significant differences in rates of loss of fixation between the 39 patients with cemented screws compared with the 55 patients treated with standard surgical technique (11% vs. 5%, $P = .74$). However, is it important to note a possible study bias because only the higher-risk patients with low bone stock in the humeral head were assigned for augmentation while the lower-risk patients were treated without augmentation. Their findings may suggest that augmentation of the higher-risk subjects was successful in achieving similar outcomes to lower-risk subjects.

Slight statistically and clinically[32] significant differences were found in our study in the Constant score and external rotation. However, owing to patients in group 1 being operated longer time ago, the rate of mortality was higher and the follow-up longer, and these factors might influence clinical scores. In addition, although cement augmentation further decreased the rate of implant-related failures and the global rate of complications, it does not seem to reduce the global rate of revision surgery for any cause. This could be related to the fact that the global rate of implant failure in our study (5%) is extremely low compared to previous published ones. Experienced teams such as Mayo Clinic published a 44% of complication rate and a 35% implant failure rate in 2020.[1] These results had been replicated in the literature during the last two decades.[4,7,12,20,28] Furthermore, we also analyzed 60 additional cases treated with locked plating at our institution by a variety of shoulder and trauma surgeons in the same period and found a 55% complication rate and 35% implant failure rate in that cohort. As opposed to simply screw cement augmentation, results in this study suggest that surgical technique and concentrating a high number of cases in a single super-specialized surgeon are probably important sources of improvement in implant fixation failures rates.

Figure 6 Cement extravasation in relation with the most inferior calcar screws, located in row E.

Table 5
Causes for revision surgery in each study group.

	Noncemented, group 1 (n = 90)	Cemented, group 2 (n = 78)
Plate removal n (%)	7 (8)	5 (6)
Fracture loss of fixation	2 (2)	-
Avascular necrosis	1 (1)	1 (1)
Plate mechanical interference	4 (4)	4 (5)
Reverse shoulder arthroplasty n (%)	-	2 (3)
Plate and screws removal and intramedulary nail fixation n (%)	1 (1)	-
Total n (%)	8 (9)	7 (9)

Table 6
Comparisons in range of motion and Constant score between study groups.

	Noncemented, group 1 (n = 90)	Cemented, group 2 (n = 64)	*P* value
Elevation degrees (mean ± DS)	125 ± 34	127 ± 37	.3
External rotation degrees (mean ± DS)	40 ± 17	48 ± 18	.001
Internal rotation spinal level	T12-L2	T12-L2	-
Constant score	86 ± 19	93 ± 19	.03

In our study, we also have observed that the pattern of fracture as per Mayo-FJD classification has a prognostic value after locking plate fixation; valgus impacted fracture showed almost 6 times higher risk of global avascular necrosis compared with other fracture patterns. The higher risk of avascular necrosis in valgus impaction fractures has also been reported before after conservative treatment[8] and had been suggested in revisions dealing with fracture sequela[2,18]

The development of partial avascular necrosis does not seem to be related to any specific fracture pattern, but to the use of cemented screws, leading to poorer results and revision surgery (Fig. 5). This complication may be related to the temperature and pressure reaction associated with PMMA injection. The risk of thermal bone tissue necrosis/apoptosis after augmentation of the PHILOS plate with PMMA has described in only one previous clinical study by Siebenburger et al[24] in which 7.7% of patients who underwent PMMA augmentation of screw tips presented with avascular necrosis, reporting two cases of global avascular necrosis and one case of partial avascular necrosis. After reviewing the cases involved specifically, we have observed that partial avascular necrosis occurred only cranial to the tips of augmented screws in row A. This finding confronts the current surgical technique of the PHILOS plate, which suggests augmenting screws from the most proximal level (row A) and extending toward the most distal level (row E), to ensure a wide distribution of cement clouds in the humeral head.

In this line, a recent study based on validated parametric computational modeling[33] reported that cement augmentation of calcar screws may provide the greatest reduction in predicted screw cut-out risk for proximal humerus plating and augmentation of these two most beneficial screws could achieve results that were equal to or better than the worst choice for augmenting four screws. However, in our series, calcar screws in row E were augmented only in 54% of cases because it was our impression, and our findings support this, cementing this row was directly associated to cement intra-articular leaking, which we believe should be avoided. In clinical studies, the surgical technique is not standardized, and there is heterogenicity in the number of cemented screws and in cemented-screws configurations. The mean number of cemented screws ranged between two and seven and screws in rows A and B were selected for cement augmentation in up to 80% of cases. On the contrary, as in our series, screws in row E were cemented in less than 50% of cases owing to calcar screw tips may lie near fracture lines and there is a risk of cement extrusion.[16,24]

After the results of our study, we believe the use of locking plate fixation with cemented screws for treatment of severely displaced proximal humeral fractures in elderly patients is a valid and reliable treatment option. We recommend avoiding cement augmentation in row A and E to avoid the risk of partial necrosis and cement leaking respectively, and concentrating the cement in the center of the head by augmenting converging screws in row B and the central screw in row D (Fig. 2). Further studies are necessary to demonstrate this last configuration is strong enough to maintain the low rate of implant failure rates we showed in this article. Other strategies to avoid partial avascular necrosis might include injecting a more limited volume of cement on row A screws, scrupulously selecting the size of the upper screws so their tip is never nearer than 6 mm from the subchondral bone (although no studies to our knowledge reported the most beneficial distance) and lowering the position of the plate and therefore the upper screws (assuming the risk of not getting purchase of the head with the low calcar screws in row E, especially in small patients). We also recommend in patients with severely displaced valgus impaction fractures needing surgical treatment, to consider RSA as opposed to open reduction and internal fixation owing to the risk of global avascular necrosis with this last technique. In our opinion, RSA should be the preferred surgical treatment in the most complex fractures as those with head split, head dislocation, associate nonrepairable rotator cuff tears, or insufficient cancellous bone stock in the head segment to maintain fixation. During the study period, 56 (18% of total surgical cases) RSAs were performed in our institution in patients older than 65 years of age sustaining an acute proximal humeral fracture.

The major strengths of this study are the cohort size of the groups, the surgery was performed by a single fellowship-trained surgeon, and a standardized surgical technique was used in all cases; however, there are some limitations. First, this was a retrospective cohort study. Second, the indication for screw-tip augmentation was not randomized: between 2009 and 2014, all proximal fractures were treated without cement, and from 2014 to 2018, when the cement injection kits were developed and available, cemented screws were used in every surgery. This leaded to different follow-up in both groups and a possible improvement in the surgeon surgical skills favoring group 2. Third, the number of cemented screws was not homogenous in all the patients.

Conclusion

Cement augmentation decreased the rate of implant failure from 9 to 1% in elderly patients after locking plate fixation of proximal humeral fractures. As per Mayo/FJD Classification, global avascular necrosis is associated to valgus impaction fractures (12% as opposed to 2% in other fracture patterns). Clinical outcome can be considered good for the majority of patients after locking plate fixation and screw augmentation, although complications reached 15% including revision surgery in 9% of cases, mainly for plate removal because of subacromial impingement.

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