J Shoulder Elbow Surg (2021) 30, 331–339

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Results of an innovative method of intramedullary fixation for displaced 4-part fractures of the proximal humerus in patients younger than 70 years

Sanjay Desai, MS, DNB, MCh, DOrth*, Rohit Jain, MBBS, MS, Vishwajeet Singh, MBBS, DNB, MRCSEd

Orthopaedic Department, Bhatia Hospital, Mumbai, India

Background: The management of displaced 4-part fractures of proximal humerus is a challenge, as it is difficult to produce consistently good results with the current methods of fixation. Varus collapse of the head and eventual failure of plate fixation have been reported in up to 45% of cases. We present an innovative method of intramedullary fixation for displaced 4-part proximal humeral fractures. The aim of this study was to present the results of an intramedullary fixation device used for displaced 4-part proximal humeral fractures in patients younger than 70 years.

Materials and methods: Fixation was performed with an intramedullary device in 30 patients with an average age of 56 years who had displaced 4-part proximal humeral fractures. The device consists of a circular staple that is impacted in the head and engages into the neck of an intramedullary uncemented stem. The stem has a sleeve that provides the ability to adjust the height and thereby facilitates accurate reduction of the tuberosity with ease. Fracture union was assessed with plain radiographs, and clinical outcomes were assessed using American Shoulder and Elbow Surgeons and Constant scores.

Results: Union was achieved in 93.33% of patients and the mean American Shoulder and Elbow Surgeons and Constant scores were 75.2 and 73.97, respectively, at an average follow-up of 25.83 months. None of the patients had tuberosity avulsion, tuberosity nonunion, or resorption. However, 2 patients had humeral head nonunion and 2 had avascular necrosis. Revision surgery was performed in 2 patients (6.67%), because of avascular necrosis in 1 and nonunion in 1.

Conclusion: In patients younger than 70 years with displaced 4-part proximal humeral fractures, the described intramedullary device provides a simple and reproducible method of internal fixation with predictable tuberosity union and shoulder function.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Displaced; four part; proximal; humerus; fractures; innovative; intramedullary; fixation

Proximal humeral fractures are the third most common type of fracture, accounting for nearly 6% of all fractures seen in the emergency department.[11] In elderly persons, this fracture has the second highest incidence of all fractures in the upper extremity.[4] Four-part proximal humeral fractures account for 3% of all humeral fractures and are regarded as the most difficult to treat.[12]

This study was approved by the Research Advisory Board and the Ethics Committee of Bhatia Hospital, Mumbai, India (no. 06/Ortho/BGH/2015).

*Reprint requests: Sanjay Desai, MS, DNB, MCh, DOrth, Shoulder & Knee Clinic, 11A Satguru, 16 French Bridge, Opp Metro Motors, Off Hughes Road Mumbai, 400007, Mumbai, India.

E-mail address: drdesaisanjay@gmail.com (S. Desai).

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2020.05.016

Complex proximal humeral fracture remains a surgical challenge owing to various problems associated with this fracture, such as the small size of the head fragment, osteoporosis, risk of tuberosity nonunion or resorption, and avascular necrosis (AVN) of the humeral head. Surgical fixation with locking plates is the most common modality used for displaced proximal humeral fractures, although other options, such as conservative treatment, percutaneous Kirschner wire fixation, proximal humeral nailing, hemiarthroplasty, and reverse shoulder arthroplasty, are available. The pain, morbidity, and prolonged rehabilitation associated with nonoperative treatment may not be acceptable to many patients. Besides, the traditional option of conservative treatment may leave some patients with persistent pain and limitation of function.[3,8] Clinical studies have demonstrated some success with the use of locking plates to treat 2- and 3-part fractures, but their clinical success for 4-part fractures remains debatable.[1,3,22,25]

The primary reason for failure of plating is loss of fixation due to varus collapse of the humeral head, leading to nonunion, malunion, and poor functional results.[21,27,33,35] This happens predominantly because it is technically difficult to achieve and maintain a stable valgus reduction in displaced, often osteoporotic 4-part proximal humeral fractures.[37]

Therefore, some surgeons prefer hemiarthroplasty for complex proximal humeral fractures. However, the tuberosity behavior following hemiarthroplasty is unpredictable, and a high incidence of tuberosity migration, nonunion, and resorption has been reported.[6,17] Use of reverse shoulder replacement for displaced 4-part proximal humeral fractures has increased lately; however, it is not the preferred choice in patients younger than 70 years.[20,40] In effect, there seems to be no consensus in the literature regarding the optimal treatment of displaced 4-part proximal humeral fractures, particularly in the age group in which preserving the humeral head is desirable.

We present a prospective study of 30 patients with displaced 4-part proximal humeral fractures treated with a unique intramedullary fixation device. The aim of our study was to provide radiologic and clinical results of patients treated with this innovative intramedullary fixation device.

Materials and methods

We performed a prospective case study of 38 patients who underwent surgical treatment of displaced 4-part proximal humeral fractures from January 2016 to October 2017. The inclusion criteria were as follows: fresh displaced 4-part proximal humeral fractures, age $<$ 70 years, no previous surgery on the fractured shoulder, no associated neurologic injury, and patients not willing to undergo conservative treatment.

We excluded 5 patients aged $\geq$ 70 years (who underwent reverse shoulder arthroplasty as primary treatment), 2 who had undergone previous surgery, and 1 with associated neurologic injury. Four patients opted for nonoperative treatment and do not form a part of this study. Thus, this study comprised 30 four-part displaced proximal humeral fractures in 30 patients who received the Just UNIC intramedullary fixation device (Evolutis, Briennon, France) (Table I). On the basis of radiographs and computed tomography scans, fractures were categorized according to the Neer fracture classification.[26] All surgical procedures were performed by the senior author, a shoulder specialist. Informed written consent was obtained from all patients.

The Just UNIC device is based on the "bilboquet" concept introduced by Doursounian et al.[14-16] The device has a staple and an intramedullary stem with a sleeve (Fig. 1). The sleeve allows adjustment of the height of the intramedullary stem, facilitating accurate reduction of the greater tuberosity. An appropriately sized staple goes in the head fragment, which is then reduced over the neck of the stem by a Morse taper. The device provides an easily reproducible valgus reduction of the head and facilitates anatomic reduction of the tuberosities, thereby providing the perfect biomechanical environment for consolidation of the tuberosities and preservation of the humeral head.

Patients were positioned in the beach-chair position with a fluoroscope in place. Both superior and deltopectoral approaches can be used depending on the distal extent of the fracture. The greater and lesser tuberosities were secured using Ethibond (No. 5) sutures (Ethicon, Somerville, NJ) passed through the tendon. The head was carefully exposed using blunt dissection. After a trial, among the 3 sizes available, the staple that covered the maximum area of cancellous bone on the fractured surface of the humeral head was impacted. The proximal end of the humeral shaft was exposed, and No. 5 Ethibond sutures were passed through 3 holes (1 for the lesser tuberosity and 2 for the greater tuberosity) drilled in the diaphysis just below the fracture to secure the tuberosities. Version of the trial implant was guided by the calcar, which is easily identified as the point where the medial and posterior borders of the metaphysis meet. The final stem and sleeve of the same size were inserted in the humeral canal. The neck of the stem was gently engaged into the staple. The stem height was then adjusted using jack-up forceps. Progressive controlled distraction was applied under fluoroscopic control until an anatomic arch was achieved, along with accurate reduction of the greater tuberosity and adequate soft-tissue tension. The stem docked in 1 of the 4 positions of the humeral sleeve, which was finally locked to the sleeve with a locking screw. The tuberosities were sutured to their anatomic positions.

The shoulder was immobilized for 6 weeks. Pendulum exercises were started 3 weeks after surgery, progressing to active-assisted exercises at 6 weeks and strengthening exercises at 12 weeks after surgery. Rehabilitation was performed for at least 6 months. The clinical parameters evaluated at final follow-up included range of motion, power, Constant score, and American Shoulder and Elbow Surgeons score.[10,29] Radiologic assessment was based on anteroposterior and axillary views. Aseptic necrosis of the humeral head was evaluated according to the Cruess classification.[13] All patients were evaluated by the senior surgeon until radiologic union was achieved. Follow-up at a minimum of 24 months was performed by a shoulder fellow.

Table I Individual results

Patient No.	Age, yr	Follow-up, mo	Constant score	ASES score	FE, °	IR	ER, °	LE, °	Union	AVN
1	66	34	71	75	110	LS	30	95	Y	N
2	56	30	88	88	140	L3	50	110	Y	N
3	54	26	10	16	15	LS	0	15	N	N
4	58	26	68	56	125	L3	40	85	Y	Y, grade 3
5	58	24	25	38	20	Buttock	10	10	N	N
6	52	24	84	73	140	L3	50	130	Y	N
7	43	24	51	46	80	LS	20	60	Y	Y, grade 4
8	43	27	92	93	155	L3	65	130	Y	N
9	55	25	88	82	140	L3	45	100	Y	N
10	65	24	78	83	130	LS	30	70	Y	N
11	62	24	78	80	140	LS	30	120	Y	N
12	59	26	78	73	110	L3	45	105	Y	N
13	58	27	74	86	115	LS	40	90	Y	N
14	57	25	71	73	100	LS	30	95	Y	N
15	52	29	84	90	130	L3	50	115	Y	N
16	61	24	82	90	130	L3	45	115	Y	N
17	58	25	82	88	130	L3	40	120	Y	N
18	57	24	57	60	70	L3	20	40	DU	N
19	54	25	78	72	115	L3	40	95	Y	N
20	56	27	70	70	105	LS	30	85	Y	N
21	64	26	78	73	155	LS	65	130	Y	N
22	59	24	84	82	140	L3	45	90	Y	N
23	66	24	78	93	130	L3	30	130	Y	N
24	44	25	92	82	140	LS	45	140	Y	N
25	49	26	88	83	110	LS	45	95	Y	N
26	52	28	76	80	115	L3	40	120	Y	N
27	54	25	76	78	100	LS	30	105	Y	N
28	45	28	76	80	130	LS	50	100	Y	N
29	63	24	84	83	130	L3	60	110	Y	N
30	60	25	78	90	70	LS	40	80	Y	N

ASES, American Shoulder and Elbow Surgeons; *FE*, forward elevation; *IR*, internal rotation; *ER*, external rotation; *LE*, lateral elevation; *AVN*, avascular necrosis; *LS*, lumbosacral; *Y*, yes; *N*, no; *DU*, delayed union.

Results

This prospective study comprised 30 patients with 4-part displaced proximal humeral fractures, with an average age of 56 years (range, 43-66 years) and a female-to-male ratio of 2:1. All fractures were displaced 4-part fractures based on the Neer classification.[26] In 60% of patients, the fracture was on the dominant side. The mean length of hospital stay was 3 days (range, 2-6 days). A size 2 staple was required for the humeral head in 60% of patients, with just 2 patients requiring a size 3 staple. A small-sized stem was used in 70% of patients. The mean follow-up duration was 25.83 months (range, 24-34 months). At final follow-up, the mean Constant score was 73.97 (range, 10-92) and the median Constant score was 78. The mean and median American Shoulder and Elbow Surgeons scores were 75.2 (range, 16-93) and 80, respectively. Mean active forward elevation was 114° (range, 15°-155°); mean active abduction, 96° (range, 15°-130°); and mean external rotation, 39° (range, 0°-65°). Regarding internal rotation, 96% of patients were able to reach up to the lumbosacral junction whereas 53% managed to reach as high as the L1 level (Table I).

Union was obtained in 93.3% of patients (Figs. 2 and 3): 27 patients had union within 16 weeks, whereas 1 patient had delayed union at 8 months. The patient with delayed union had osteolysis around the implant, perhaps due to micromotion following aggressive mobilization. His post-operative rehabilitation was therefore slowed down, and subsequently, the fracture united at 8 months after surgery. This patient had a Constant score of 57 with no signs of AVN. No neurologic complications or infections occurred in this series. However, nonunion developed in 2 patients, and AVN of the humeral head occurred in 2 (13% complication rate). In 1 of the 2 patients with nonunion, failure occurred because of surgical error. The patient had a butterfly fragment (Fig. 4, *A* and *B*) in the humeral shaft that was not addressed during surgery, due to which the humeral stem was unstable. This led to secondary displacement of the construct into varus (Fig. 4, *C*). Reverse

Figure 1 Parts of Just UNIC device: humeral head staple and intramedullary stem, which slides and docks into uncemented humeral sleeve.

shoulder arthroplasty was performed 2 months after primary surgery (Fig. 4, *D*). During the revision surgical procedure, it was possible to remove the implant without much difficulty. In the second patient with nonunion, the staple had lost its hold on the head, which eventually slipped into varus. This patient had a neurologic problem affecting the lower limbs with an abnormal gait; this perhaps led to premature overloading of the arm. She was offered revision surgery but did not agree. The overall revision rate was 6.7% (2 patients), with reverse arthroplasty in 1 patient and hemiarthroplasty in the other patient, who had grade 4 AVN. The latter patient with AVN had minimal symptoms and therefore chose not to undergo revision surgery. No malunion or tuberosity migration was seen in any patient.

Discussion

An increase in the indications for reverse shoulder arthroplasty for 4-part displaced proximal humeral fractures has been shown in recent years.[30,39] One reason for this increase is the poor and inconsistent results of fixation as well as hemiarthroplasty.[3,6] Despite the improved understanding of fracture patterns and improved implant designs such as locking plates and variable-angle screws, these fractures continue to be a challenge, without any technique providing consistently good results. In a systematic review of 66 articles involving 2155 patients, Lanting et al[23] found no clear consensus or guidelines regarding the best treatment for these fractures. Schumaier and Grawe[32] evaluated percutaneous techniques, intramedullary nails, locking plates, and arthroplasty for the treatment of displaced proximal humeral fractures in elderly patients and concluded that there is no clear evidence-based treatment of choice for these fractures in elderly patients. The intramedullary or extramedullary devices available to date do not give sufficient support to the humeral head; as a result, the head often tilts into varus postoperatively or the hardware penetrates into the head.[32] The PROFHER (Proximal Fracture of the Humerus: Evaluation by Randomization) trial, which recruited 250 patients with a mean age of 66 years, concluded that there is no difference in the outcomes between operative and nonoperative patients.[28] They pooled all types of proximal humeral fractures (18 one-part fractures, 128 two-part fractures, and 104 three- or four-part fractures), making it very difficult to interpret the results, particularly those of the more severe 4-part fractures. Besides, this inference does not necessarily reflect the good results of conservative treatment but rather the poor results of current fixation techniques.

Several studies have found high rates of complications with the use of plates, such as varus displacement of the head fragment, screw penetration, and impingement.[3,9,21,34,35,36,37] Kavuri et al,[21] in a systematic review, reported an overall intra-articular screw penetration rate of 9.5% and a reoperation rate of 13.8%. Sudkamp et al[36] reported a 34% complication rate in their study of 155 patients; of these complications, 40% were directly related to the initial surgical procedure, with primary screw perforation (14%) being the most common. The subacromial impingement rate ranges from 1% to 5%, primarily owing to poor intraoperative plate positioning.[21,35] A systemic review by Thanasas et al[37] reported screw cutout in 11.6% of cases and reoperation in 13.7%. They suggested that these complications could be due to the rigidity of the implant with inadequate medial support. Varus collapse was reported as the most common complication (16.3%) in a review by Sproul et al.[35] In osteoporotic bone especially, an initial varus pattern has a poor outcome with locking plates, as the screws are unable to hold the humeral head out of varus because of poor bone quality.[35] Varus collapse is responsible for both secondary impingement and screw penetration into the articular surface of the joint. Clavert et al,[9] in their study of 73 patients, found a mean final Constant score of 62.3, a screw cutout rate of 13.7%, and a secondary displacement rate of 8.2%. Barlow et al[3] reported high failure and reoperation rates with proximal humerus locking plates in elderly patients older than 60 years. Around 45% of 4-part fractures treated by this method failed, and 18% of patients underwent second surgical procedures.

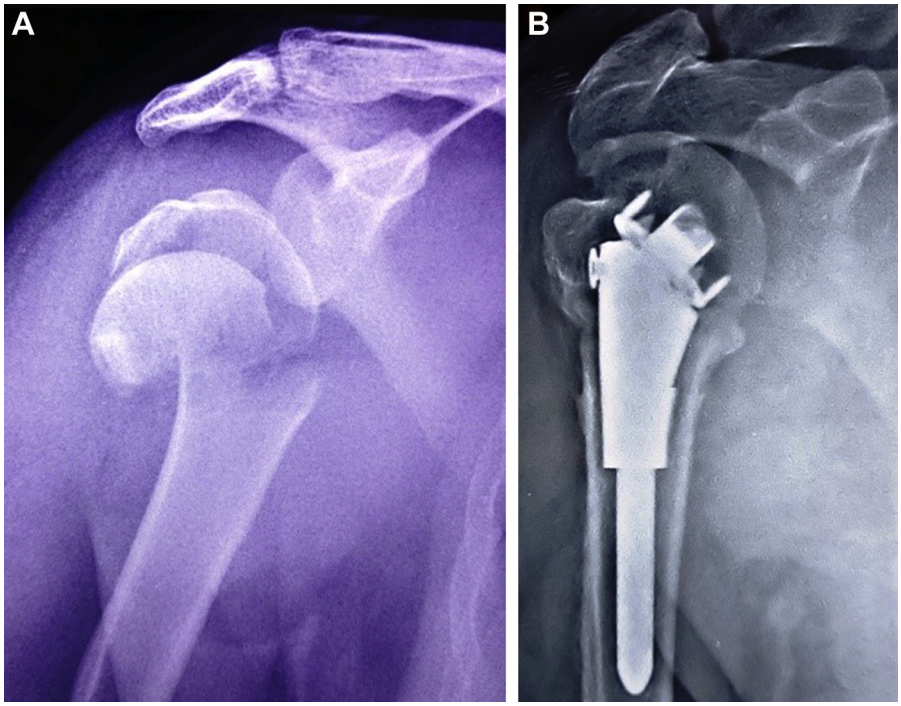

Figure 2 **(A)** Preoperative anteroposterior radiograph showing displaced 4-part proximal humeral fracture. **(B)** Anteroposterior radiograph at final follow-up showing restored anatomy with humeral head and tuberosities united.

Reoperation is a very important measure of how successful primary surgery is. Silverstein et al[33] reported 11 reoperations (20%) in their study of 54 patients, mostly owing to impingement pain or functional impairment. Solberg et al[34] reported a 10% reoperation rate, mostly owing to secondary loss of fixation with conversion to hemiarthroplasty. Laux et al[24] reviewed causes of revision surgery and methods to decrease them. They reported a revision rate of up to 25% with locking plates; these revisions were mostly because of varus malalignment and secondary screw cutout. In our series, revision was required in 2 patients (6.67%); in one of these patients, this was because of the surgical error of not fixing a large butterfly fragment (Fig. 4, *A* and *B*). Intramedullary nailing may have a role in 2- or 3-part fractures; however, its role in complex displaced 4-part fractures in which the proximal humerus has burst is questionable.[19,41]

Despite the substantial progress in shoulder replacement and particular attention being paid to repairing the tuberosities, hemiarthroplasty for proximal humeral fractures has given discouraging clinical results, with poor range of movement and significant functional deficit.[2,6,7] Solberg et al[34] reported tuberosity nonunion as the most common complication (15%) that resulted in progressive tuberosity migration, which required revision and bone grafting. They reported that the mean final Constant score was much lower in patients with tuberosity nonunion (52.9) than in those in whom the tuberosities united and was directly related to older age group patients. Boons et al,[7] in a randomized controlled trial, found the Constant score at 3 and 12 months' follow-up to be 48 and 64, respectively; these scores were very comparable to those in patients on whom the authors did not operate, suggesting no added benefit with humeral head replacement. The unfavorable result obtained is due to the unpredictable behavior of the tuberosities. Initial tuberosity malposition (27%) or migration (23%) was noted with poor outcomes of hemiarthroplasty in a study of 66 patients with displaced proximal humeral fractures conducted by Boileau et al.[6] The final tuberosity malposition was observed in >50% of cases and it correlated with a low average Constant score of 56. Thorsness et al[38] retrospectively reviewed 30 patients with complex fractures that underwent internal fixation and hemiarthroplasty (15 in each group); they concluded that patient-reported outcomes were better in the fixation group but the fixation group had a higher revision rate (22%).

Because of these well-documented difficulties with internal fixation and hemiarthroplasty, the use of reverse shoulder arthroplasty has been proposed for complex proximal humeral fractures. However, there is a consensus that in patients younger than 70 years, a humeral head–preserving option is preferable over reverse shoulder arthroplasty,[20,40] hence the need to provide a method of internal fixation that is both reliable and reproducible.

The unique intramedullary fixation device used in this study (Fig. 1) is based on the bilboquet concept imagined in the 1990s by Professor L. Doursounian, which uses a cylindrical staple that provides a platform of support for the

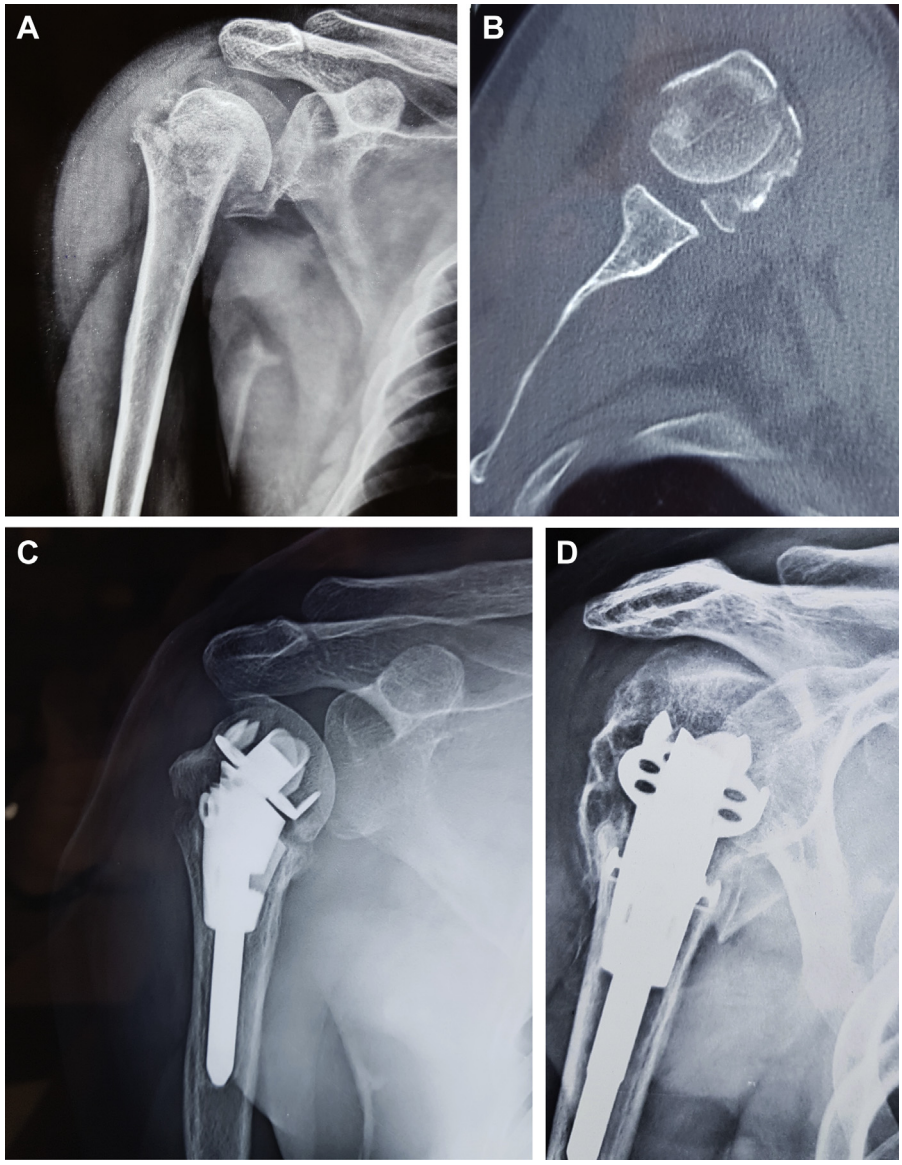

Figure 3 **(A)** Preoperative anteroposterior radiograph showing displaced 4-part proximal humeral fracture. **(B)** Axial-cut computed tomography scan showing displaced 4-part proximal humeral fracture with small head fragment. **(C)** Anteroposterior radiograph at final follow-up showing well-reduced and -healed fracture. **(D)** Radiograph showing well-healed fracture.

humeral head both centrally and peripherally with little risk of going through the head or creating varus tilt of the head. The basic construct of the device facilitates natural anatomic realignment of the humerus head with ease, thereby providing a perfect biomechanical environment for tuberosity healing. This system also has the advantage of being intraosseous, thereby avoiding any periosteal stripping or impingement. The initial design did not have the ability to adjust the stem height, and the stem was cemented. The intramedullary device used in this series brings an important innovation by implanting a ''cementless humeral sleeve.'' Besides, the distance between the humeral head and shaft is adjustable, thus facilitating anatomic reduction of the tuberosity. In fact, the greater tuberosity tends to naturally fall in place. We would, however, caution against the use of this device in patients in whom the fracture extends into the shaft of the humerus, rendering the uncemented humeral component unstable (Fig. 4, *A-C*).

The rate of varus tilt in this series (Fig. 4, *C*) was 3.33%, which is comparable to the finding in a study performed by Doursounian et al,[14] in which varus tilt was reported in 3 cases (5%) in a series of 61 patients. Doursounian et al,[16] in a prospective study of 22 patients, reported no secondary tilting, nor did they encounter any nonunion or migration of the tuberosities. In a series comprising 26 patients, Doursounian et al[15] reported 1 case of pseudarthrosis of the tuberosity, and in another study, published in 2005,

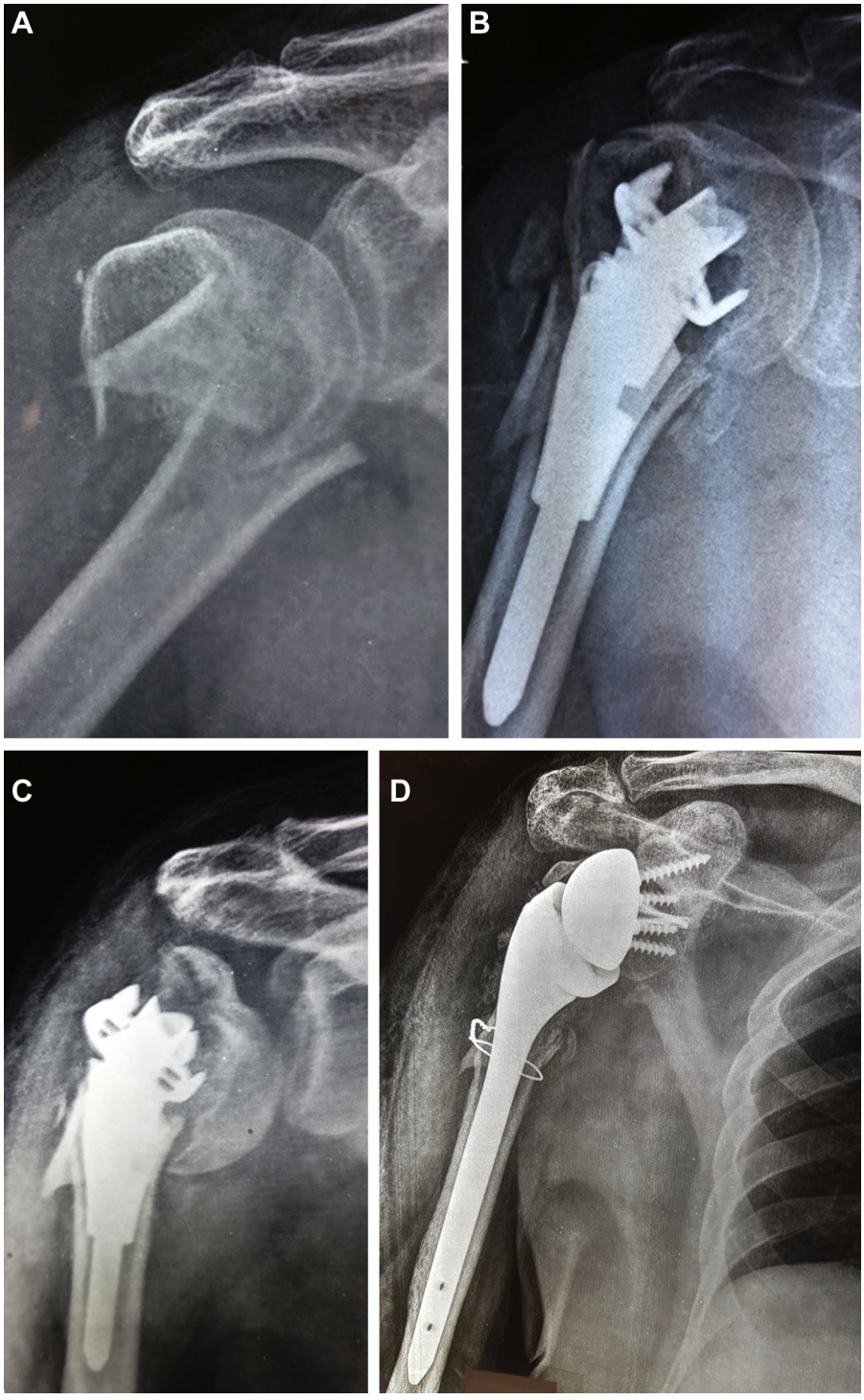

Figure 4 **(A)** Displaced 4-part proximal humeral fracture with large butterfly fragment on preoperative anteroposterior radiograph. **(B)** Postoperative anteroposterior radiograph showing well-placed implant but unattended butterfly fragment. **(C)** Two-month follow-up anteroposterior radiograph depicting unstable stem and varus collapse of humeral head. **(D)** Immediate postoperative radiograph following revision to reverse shoulder arthroplasty.

comprising 61 cases, they reported only 2 such cases.[14] In our series, complete reduction of the tuberosities was obtained in all cases, with no case of tuberosity migration. The mean Constant score was 74.0, with a mean follow-up of 25.8 months. This is comparable to the mean follow-up of 34 months in the study of 22 patients performed by Doursounian et al.[16] The major difference in our study compared with the studies conducted by Doursounian et al[14-16] was the postoperative rehabilitation protocol. Our rehabilitation was relatively slow because we believe that

the staple fixation in the head may not be strong; however, the overall Constant score was comparable to scores in the studies of Doursounian et al.[14-16] One of the concerns when using the described device is the risk of AVN. In the series of 61 patients by Doursounian et al,[14] the AVN rate was 15% in 3-part fractures and 37% in 4-part fractures; however, only 5 of the 22 patients with AVN underwent conversion to hemiarthroplasty. In another series, of 22 patients, 5 had AVN but none underwent conversion to hemiarthroplasty.[16] In our series, there were 2 cases of AVN (6.7%). One of the two patients with AVN underwent conversion to hemiarthroplasty. However, the second patient with AVN had minimal symptoms and therefore did not opt for arthroplasty. The incidence of AVN with this device in our series was not higher than that reported using other methods of fixation for proximal humeral fractures.[5,42] In our experience, these cases of AVN are often functionally well tolerated, particularly if there is successful anatomic union of the tuberosities with a well-functioning rotator cuff. This is similar to the experience reported by Gerber et al[18] and other authors.[14,15,31]

To our knowledge, this is the first non-designer study, with the implant being used for only the most challenging 4-part displaced proximal humeral fractures, unlike the studies conducted by Doursounian et al.[14-16] In patients younger than 70 years with displaced 4-part proximal humeral fractures who are willing to undergo surgery, we prefer this intramedullary device over other available fixation devices. We admit that an inherent weakness of the study is lack of randomization and a control group. The selection of patients to receive this implant, among others with 4-part fractures, was based on surgeon discretion. In addition, a longer follow-up period is required as late osteonecrosis might develop in a small number of patients.

Conclusion

The currently available methods of fixation or hemiarthroplasty for displaced 4-part proximal humeral fractures do not give consistently good results. In patients younger than 70 years, in whom preserving the humeral head is desirable, the described intramedullary device provides a simple and reproducible method of internal fixation with predictable tuberosity union and shoulder function.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Agudelo J, Schurmann M, Stahel P, Helwig P, Morgan SJ, Zechel W, et al. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma 2007;21:676-81. https://doi.org/10.1097/BOT.0b013e31815bb09d
2. Antuna SA, Sperling JW, Cofield RH. Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up. J Shoulder Elbow Surg 2008;17:202-9. https://doi.org/10.1016/j.jse.2007.06.025
3. Barlow JD, Logli A, Steinmann SP, Sems SA, Cross WC, Yuan BJ, et al. Locking plate fixation of proximal humerus fractures in patients over 60 continues to be associated with a high complication rate. J Shoulder Elbow Surg 2019;28:e213-4. https://doi.org/10.1016/j.jse.2018.11.028
4. Baron JA, Barrett JA, Karagas MR. The epidemiology of peripheral fractures. Bone 1996;18(Suppl):S209-13.
5. Bogner R, Hübner C, Matis N, Auffarth A, Lederer S, Resch H. Minimally-invasive treatment of three- and four-part fractures of the proximal humerus in elderly patients. J Bone Joint Surg Br 2008;90:1602-7. https://doi.org/10.1302/0301-620X.90B12.20269
6. Boileau P, Krishnan SG, Tinsi L, Walch G, Coste JS, Molé D. Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus. J Shoulder Elbow Surg 2002;11:401-12. https://doi.org/10.1067/mse.2002.124527
7. Boons HW, Goosen JH, Grinsven SV, Susante JL, Loon CV. Hemiarthroplasty for humeral four-part fractures for patients 65 years and older: a randomized controlled trial. Clin Orthop Relat Res 2012;470:3483-91. https://doi.org/10.1007/s11999-012-2531-0
8. Calvo E, Morcillo D, Foruria AM, Redondo-Santamaria E, Osorio-Picorne F, Caeiro JR. Nondisplaced proximal humeral fractures: high incidence among outpatient-treated osteoporotic fractures and severe impact on upper extremity function and patient subjective health perception. J Shoulder Elbow Surg 2011;20:795-801. https://doi.org/10.1016/j.jse.2010.09.008
9. Clavert P, Adam P, Bevort A, Bonnomet F, Kempf JF. Pitfalls and complications with locking plate for proximal humerus fracture. J Shoulder Elbow Surg 2009;19:489-94. https://doi.org/10.1016/j.jse.2009.09.005
10. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;214:160-4.
11. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury 2006;37:691-7. https://doi.org/10.1016/j.injury.2006.04.130
12. Court-Brown CM, Garg A, McQueen MM. The epidemiology of proximal humeral fractures. Acta Orthop Scand 2001;72:365-71.
13. Cruess LR. Osteonecrosis of bone. Current concepts as to etiology and pathogenesis. Clin Orthop Relat Res 1986;208:30-9.
14. Doursounian L, Candelier G, Werther JR, Jacquot F, Grimberg J. The bilboquet device for fractures of the proximal humerus in the elderly. Osteosynthesis Trauma Care 2005;13:164-74. https://doi.org/10.1055/s-2005-836624
15. Doursounian L, Grimberg J, Cazeau C, Jos E, Touzard RC. A new internal fixation device for fractures of the proximal humerus—the bilboquet device: a report on 26 cases. J Shoulder Elbow Surg 2000;9:279-88.
16. Doursounian L, Kilinc A, Cherrier B, Nourissat G. Complex proximal humeral fractures: a prospective study of 22 cases treated using the

"bilboquet" device. Orthop Traumatol Surg Res 2011;97:58-66. https://doi.org/10.1016/j.otsr.2010.06.015
17. Frankle MA, Greenwald DP, Markee BA, Ondrovic LE, Lee WE. Biomechanical effects of malposition of tuberosity fragments on the humeral prosthetic reconstruction for four-part proximal humerus fractures. J Shoulder Elbow Surg 2001;10:321-6.
18. Gerber C, Hersche O, Berberat C. The clinical relevance of post-traumatic avascular necrosis of the humeral head. J Shoulder Elbow Surg 1998;7:586-90.
19. Hao TD, Huat AWT. Surgical technique and early outcomes of intramedullary nailing of displaced proximal humeral fractures in an Asian population using a contemporary straight nail design. J Orthop Surg 2017;25:1-9. https://doi.org/10.1177/2309499017713934
20. Jobin CM, Galdi B, Anakwenze OA, Ahmad CS, Levine WN. Reverse shoulder arthroplasty for the management of proximal humerus fractures. J Am Acad Orthop Surg 2015;23:190-201. https://doi.org/10.5435/JAAOS-D-13-00190
21. Kavuri V, Bowden B, Kumar N, Cerynik D. Complications associated with locking plate of proximal humerus fractures. Indian J Orthop 2018;52:108-16. 10.4103%2Fortho.IJOrtho_243_17.
22. Kumar C, Gupta AK, Nath R, Ahmad J. Open reduction and locking plate fixation of displaced proximal humerus fractures. Indian J Orthop 2013;47:156-60. 10.4103%2F0019-5413.108903.
23. Lanting B, MacDermid J, Drosdowech D, Faber KJ. Proximal humeral fractures: a systematic review of treatment modalities. J Shoulder Elbow Surg 2008;17:42-54. https://doi.org/10.1016/j.jse.2007.03.016
24. Laux CJ, Grubhofer F, Werner CML, Simmen HP, Osterhoff G. Current concepts in locking plate fixation of proximal humerus fractures. J Orthop Surg Res 2017;12:137. https://doi.org/10.1186/s13018-017-0639-3
25. Moonot P, Ashwood N, Hamlet M. Early results for treatment of three- and four-part fractures of the proximal humerus using the PHILOS plate system. J Bone Joint Surg Br 2007;89:1206-9. https://doi.org/10.1302/0301-620X.89B9.18528
26. Neer CS II. Displaced proximal humeral fractures. Part I. Classification and evaluation. J Bone Joint Surg Am 1970;52:1077-89.
27. Owsley K, Gorczyca JT. Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures. J Bone Joint Surg Am 2008;90:233-40. https://doi.org/10.2106/JBJS.F.01351
28. Rangan A, Handoll H, Brealey S, Jefferson L, Keding A, Martin BC, et al. Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. JAMA 2015;313:1037-47. https://doi.org/10.1001/jama.2015.1629
29. Richards RR, An KN, Bigliani LU, Friedman RJ, Gartsman GM, Gristina AG, et al. A standardized method for the assessment of shoulder function. J Shoulder Elbow Surg 1994;3:347-52.
30. Sabesan VJ, Lombardo D, Petersen FG, Weisman M, Ramthun K, Whaley J. National trends in proximal humerus fracture treatment patterns. Aging Clin Exp Res 2017;29:1277-83. https://doi.org/10.1007/s40520-016-0695-2
31. Schai P, Imhoff A, Preiss S. Comminuted humeral head fractures: a multicentre analysis. J Shoulder Elbow Surg 1995;4:319-30.
32. Schumaier A, Grawe B. Proximal humerus fractures: evaluation and management in the elderly patient. Geriatr Orthop Surg Rehabil 2018;9:1-11. 10.1177%2F2151458517750516.
33. Silverstein MP, Yirenkyi K, Haidukewych G, Koval KJ. Analysis of failure with the use of locked plates for stabilization of proximal humerus fractures. Bull Hosp Jt Dis 2015;73:185-9.
34. Solberg BD, Moon CN, Franco DP, Paiement GD. Surgical treatment of three and four-part proximal humeral fractures. J Bone Joint Surg Am 2009;91:1689-97. https://doi.org/10.2106/JBJS.H.00133
35. Sproul RC, Iyengar JJ, Devcic Z, Feeley BT. A systematic review of locking plate fixation of proximal humerus fractures. Injury 2011;42:408-13. https://doi.org/10.1016/j.injury.2010.11.058
36. Sudkamp N, Bayer J, Hepp P, Voigt C, Oestern H, Kaab M, et al. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. Results of a prospective, multicenter, observational study. J Bone Joint Surg Am 2009;91:1320-8. https://doi.org/10.2106/JBJS.H.00006
37. Thanasas C, Kontakis G, Angoules A, Limb D, Giannoudis P. Treatment of proximal humerus fractures with locking plates: a systematic review. J Shoulder Elbow Surg 2009;18:837-44. https://doi.org/10.1016/j.jse.2009.06.004
38. Thorsness R, Shields E, Chen RE, Owens K, Gorczyca J, Voloshin I. Open reduction and internal fixation versus hemiarthroplasty in the management of complex articular fractures and fracture-dislocations of the proximal humerus. J Shoulder Elbow Arthroplasty 2017;1:1-7. 10.1177%2F2471549217709364.
39. Urch E, Dines JS, Dines DM. Emerging indications for reverse shoulder arthroplasty. Instr Course Lect 2016;65:157-69.
40. Werthel JD, Sirveaux F, Block D. Reverse shoulder arthroplasty in recent proximal humerus fractures. Orthop Traumatol Surg Res 2018;104:779-85. https://doi.org/10.1016/j.otsr.2018.07.003
41. Wong J, Newman JM, Gruson KI. Outcomes of intramedullary nailing for acute proximal humerus fractures: a systematic review. J Orthop Traumatol 2016;17:113-22. https://doi.org/10.1007/s10195-015-0384-5
42. Xu J, Zhang C, Wang T. Avascular necrosis in proximal humeral fractures in patients treated with operative fixation: a meta-analysis. J Orthop Surg Res 2014;9:31. https://doi.org/10.1186/1749-799X-9-31