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ORIGINAL ARTICLE

Complex humeral head fractures treated with blocked threaded wires: maintenance of the reduction and clinical results with two different fixation constructs

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Background: Locking plates are the gold standard for treatment of 3-part humeral head fractures, although major complications range from 9% to 36%. Percutaneous techniques may allow vascular supply preservation, maintenance of fracture hematoma, scarce blood loss. Many configurations with Kirschner wires can be performed, generating confusion on result interpretation. We studied the correlation between system configuration, stability, and clinical results in patients with 3-part humeral head fractures treated with the same fixation system but with 2 different biomechanical constructs.
Materials and methods: There were 52 consecutive patients (19 men, 33 women; mean age, 63.1 [standard deviation, 5.6] years; range, 48-82 years) with Hertel 7 humeral head fractures. Two fixation constructs composed of 3 couples (construct A) or 4 couples (construct B) of blocked threaded wires were used in 17 and 35 patients, respectively. At the final follow-up, the individual relative Constant Score (irCS) and visual analog scale were measured. Radiographic evaluation according to the Bahr criteria was performed. Statistical analysis was performed.
Results: The mean follow-up was 22 months. The mean irCS at the final follow-up was 89.7%. The mean irCS in patients treated with construct A and construct B was 86% and 93%, respectively ($P = .043$). One nonunion and 2 superficial infections occurred (6%). The postoperative reduction was excellent in 97% of patients and remained excellent in 89%. The mean postoperative neck shaft angle was 135.0° (construct A: 134.7°; construct B: 135.1°), and the final neck shaft angle was 132.9° (construct A: 131.3°; construct B: 133.8°; $P = .047$).
Conclusions: The functional and radiologic outcomes obtained with percutaneous fixation or locking plates are similar; however, the percentage of major complications after percutaneous treatment is lower. Results of percutaneous fixation depend on the biomechanical construct.

This study did not require ethics committee approval according to Italian law.

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Fracture reduction, when feasible, has always been considered the most important requirement to obtain a satisfactory functional result after a 3-part humeral head fracture. Over time, numerous types of synthesis have been proposed to maintain the reduction. Locking plates are currently considered the gold standard for the internal fixation of these fractures. Literature indicates that the percentage of late common complications (avascular necrosis, nonunion, or sintering of screws) after the use of these plates ranges from 9% to 36%.[7,10,11,14]

Whether locking plates could contribute to compromising humeral head blood perfusion is unclear.[2,9] In particular, we do not know whether perfusion could be further compromised by periosteal damage consequent to plate fixation or by the numerous perforations of the humeral head made by the cephalic screws.

Percutaneous techniques may allow displaced fractures of the proximal humerus to be reduced and stabilized by Kirschner wires alone or wires clamped into a locking device.[4,5,16] The advantages of these techniques are the possible preservation of the vascular supply to the bone fragments,[8] the shorter duration of the intervention,[5] the maintenance of the fracture hematoma, scarce blood loss, and the possibility of surgery with brachial plexus block.[13]

The percutaneous pinning technique is not free from criticism, however. Detractors believe that stability is not enough to ensure a proper maintenance of the intraoperative reduction and to allow an early mobilization. In addition, migration of Kirschner wires during the early postoperative period may be a common complication.[4,17]

Percutaneous pinning allows many configurations to be obtained because threaded wires and rods can be placed in different areas and directions according to the conditions of the bone and soft tissue and the surgeon's experience. All this generates confusion on the interpretation of results reported in literature because of the poor reproducibility of the technique.

To our knowledge, no study to date has evaluated the correlation between system configuration, system stability, and clinical results. We studied these parameters in 2 groups of patients with fractures of the surgical neck and greater tuberosity treated with the same fixation system but with 2 different biomechanical constructs.

Materials and methods

The study cohort was represented by 52 patients (19 men and 33 women), who were a mean age of 63.1 years (standard deviation [SD], 5.6; range, 48-82 years). The right shoulder was affected in 29 patients.

The diagnosis and classification of fractures were based on trauma series radiographs of the involved shoulder. Computed tomography scans were obtained in all cases to better evaluate the fracture pattern and to plan surgery. Fractures were classified according to the Codman-Lego system,[9] and the varus/valgus and impaction/distraction angulation of the upper humerus were assessed as described by Majed et al.[12]

Exclusion criteria were chemotherapy, anticancer therapies in progress, sepsis, septic arthritis, osteomyelitis or other ongoing infectious processes, other systemic infectious processes, previous shoulder operations, patients receiving chronic therapy with steroids or nonsteroidal anti-inflammatory drugs, and patients with severe metabolic disorders.

Inclusion criteria were consecutive patients treated in 2 different institutions with the Galaxy Fixation System (Orthofix Srl, Bussolengo, Verona, Italy), with 2 different fixation constructs, with a Hertel 7 proximal humeral fracture (surgical neck and greater tuberosity).

Surgical technique

Patient was placed in semibeach chair position (20° of inclination) with the image intensifier on the same side of the fracture. Fluoroscopy was always be done in anteroposterior and axillary directions to confirm configuration, position, and size of the fragments.

All patients received "short antibiotic therapy," which consists of 2 g cefazolin 30 minutes before surgery and 2 g 8 and 16 hours after surgery.

The threaded wires (2.5-mm diameter, fully threaded at the terminal 70 mm) were introduced through the lateral cortical bone of the humeral shaft 2 to 3 cm distal to the surgical neck with a distal-proximal direction to the humeral head. In the sagittal plane, the wires had divergent directions, similar to the directions of the humeral load peaks described by Bergmann et al.[3] According to the latter study, the load peaks on the humeral head occur in a superomedial direction in the frontal plane and a superoposterior direction in the sagittal plane within a very small range of direction.[3] Initially, wires had not to cross the surgical neck.

The reduction of displaced fractures by manipulation was attempted at this time. When a satisfactory reduction was not obtained, the varus/valgus deviation and the ante/retrotorsion of the humeral head were corrected using a blunt elevator introduced through a 2-cm skin incision and centered on the humeral head fracture. When the reduction was achieved, the 2 wires were inserted through the surgical neck into the humeral head. A distance of 5 mm between the tip of the most cranial wire and the cortex of the humeral was maintained to avoid intraoperative humeral head perforation and postoperative humeral head impaction.[4]

Reduction of the greater tuberosity, when dislocated, was done with a threaded wire or with a hook to grasp the cuff tendons and

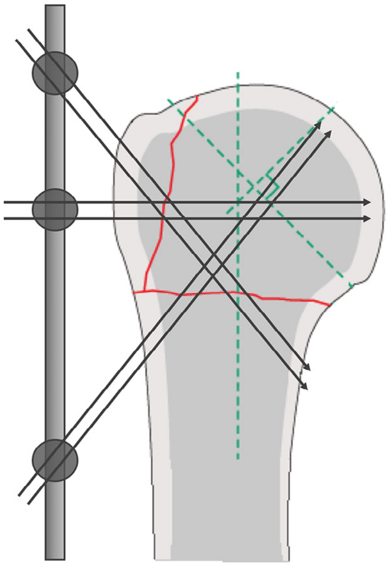

Figure 1 Fixation construct A: 3 couples of threaded wires are connected by clamps and a single bar.

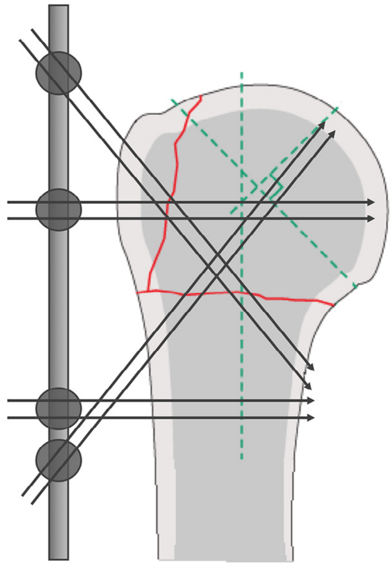

Figure 2 Fixation construct B: 4 couples of threaded wires are connected by clamps and a single bar. Two additional diaphyseal wires are placed to stabilize the system.

relocate the tuberosity in the correct position. Fixation of tuberosity was achieved with 2 threaded wires introduced with a craniocaudal and lateromedial direction as far as to transfix the uppermost medial cortex of the humeral diaphysis. Two additional threaded wires were introduced to fix the greater tuberosity to the humeral head.

Finally, the threaded wires were connected by clamps and the 2 couples of wires with a single bar (construct A, Fig. 1).

In the same period in 35 cases in another center, 2 additional threaded wires were introduced in the upper portion of the humeral diaphysis, 4 to 5 cm distally to the surgical neck. As for the other group, the 4 couples of threaded wires were connected by a single rod (construct B; Figs. 2 and 3). Construct B is composed of 4 couples of wires: A, B, C and D; rods A and B are transverse and cross the line fracture, rod C is located in the humeral head, and rod D is diaphyseal and completely below the fracture line. The main feature of this system is that the 4 rods are coplanar; that is, they lie on the same plane, thus forming a rigid system.

An analysis of the possible movements for the humeral head and the differences between the 2 fixation constructs basing on biomechanical considerations is as follows:

- **Torsion**. In this case, the bone—below the line of fracture—may rotate around its axis with respect to the humeral head. This movement is not possible if rod D is present. Indeed, the system is anchored to the bone in 3 points (2 for rod D and 1 for rod A), identifying a plane that is kept by the system in a fixed position. Any rotation of the bone (inside the arm) would change this relative position: hence, no rotation is possible.
- **Translation**. In this case, the bone—below the line of fracture—may slide with respect to the humeral head. This movement is impossible due to the presence of rod D, which keeps the bone at a fixed distance with respect to the external structure.

After surgery, a true anteroposterior (1.2-m distance from x-ray source from the shoulder with a beam magnification n of 10%) and an axillary radiographs (10% of beam magnification) were obtained.

Postoperative management

The patient was placed in a sling at 15° of shoulder abduction, and shoulder immobilization was maintained for 30 days. The wires were antiseptically treated and disinfected weekly with chlorhexidine 2% and iodopovidone 10%. The patient was asked to start wrist, hand, and finger exercises, and flexion/extension of the elbow starting from the first day postoperatively.

After 1 month, the sling was removed, and passive shoulder girdle exercises and passive shoulder motion were allowed. Actively assisted shoulder motion was started, not exceeding 120° of flexion and abduction, with the supervision of a physiotherapist. At the 45th day postoperatively, the Galaxy System was removed in the operating room with a mean surgical time of 5 minutes, and patients started full active exercises.

Clinical evaluation

Clinical evaluation was performed after 2, 3, 4, 6, 9, and 12 months and, when possible, 18 and 24 months after surgery. The individual relative Constant-Murley score (irCS)[6] was calculated at the final follow-up. None had contralateral shoulder dysfunction. Pain was measured on the visual analog scale (VAS).

Radiographic evaluation

Anteroposterior and axillary view radiographs were performed 15 and 45 days after surgery to check reduction maintenance and initial fracture healing, allowing us to remove the system, and then after 3, 6, 9, 12, 18, and 24 months after surgery.

The accuracy of fracture reduction was assessed on radiographs following the Bahrs et al[1] criteria: (1) greater tuberosity with a side-to-side difference distance of <5 mm, (2) no excessive varus or valgus (±15°) of the head fragment on the anteroposterior view, and (3) no increased retrotorsion or antetorsion (±15°) on the

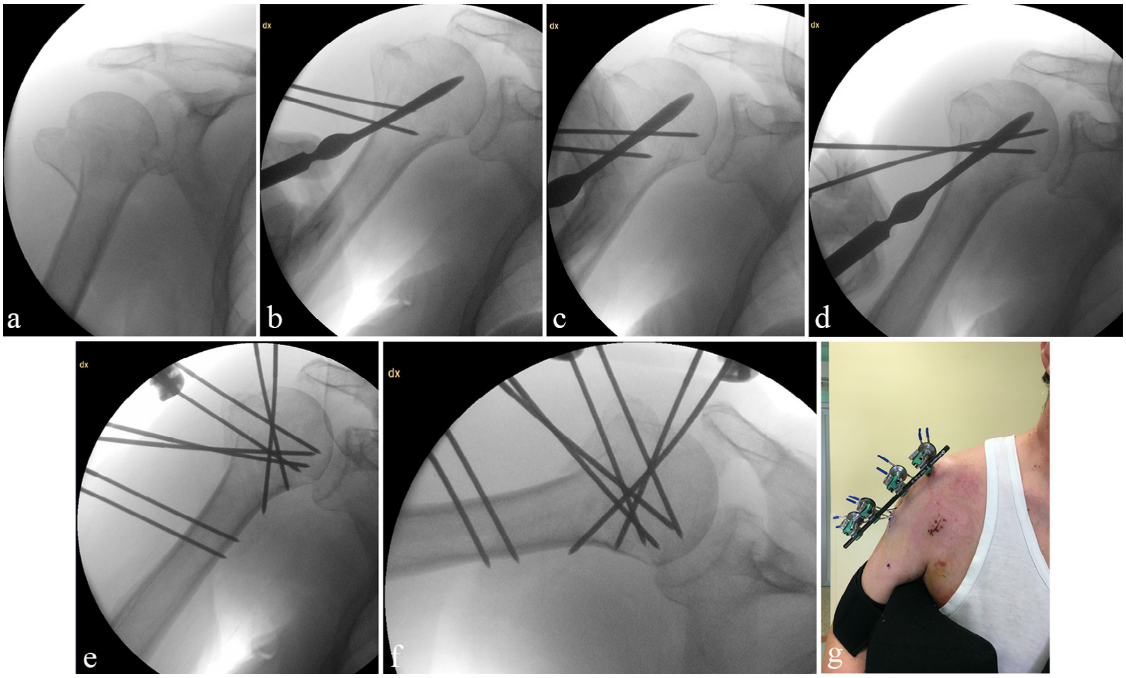

Figure 3 (**a**) Hertel 7 proximal humeral fracture in a 61-year-old man. (**b-d**) The threaded wires were introduced through the lateral cortical bone of the humerus shaft 2- to 3-cm distal to the surgical neck. Reduction was obtained using a blunt elevator introduced through a 2-cm skin incision; when the reduction was achieved, the two wires are inserted through the surgical neck into the humeral head. (**e** and **f**) once the reduction was obtained, fixation construct B was performed. (**g**) Construct B configuration is shown. A 2-cm skin incision was performed to reduce the fracture. A sling in 15° of shoulder abduction was placed after surgery**.**

axillary view. To evaluate the quality of the reduction, a score 0 was assigned if all 3 criteria were satisfied (excellent), a score 1 was given if 2 of the 3 criteria were met (good), and a score 2 (fair) or 3 (poor) was assigned if 1 or 0 criteria, respectively, were satisfied. The same criteria were used to classify the accuracy of reduction.

All images were examined on diagnostic quality liquid crystal display monitors using DICOM (Digital Imaging and Communication in Medicine; National Electrical Manufacturers Association, Rosslyn, VA, USA)–compliant grading software (IMPACS Web 1000; Agfa, Mortsel, Belgium).

Statistical analysis

Calculation of sample size was done using G*Power 3.1.9 software (Heinrich-Heine-University, Dusseldorf, Germany). According to post hoc Wilcoxon-Mann-Whitney test, assuming an α-value of 0.05 (sensitivity of 95%) and a sample group of 34 patients, the power achieved is 80% (β = 0.2).

Metric variables are reported as the mean (SD). For unpaired group comparisons, the Mann-Whitney *U* test was used. All statistical tests were 2-sided. *P* values of <.05 were considered as statistically significant. All statistical calculations were performed using R 3.4.1 software (R Foundation for Statistical Computing, Vienna, Austria; https://www.r-project.org).

Results

The mean surgical time was 37 minutes (range, 27-80 minutes), and the interval between trauma and surgery was 3 days (range, 1-6 days). No difference in surgical time between the 2 clinics was found. The mean follow-up was 22 months (range, 14-28 months).

The only major complication was a fracture nonunion in a 78-year-old woman. Two superficial infections of the proximal couple of wires (67-year-old man and 74-year-old woman) were treated with 5 days of oral antibiotics (amoxicillin/clavulanic acid), obtaining infection resolution. No body mass index >30 kg/m^2 and diabetes were present in the 3 patients.

Construct A was used to treat 17 patients (mean age, 63.2; range, 46-78 years) and construct B was used in 35 patients (mean age, 65.4; range, 48-82 years).

The mean irCS at the final follow-up was 89.7%; in detail, the mean irCS of patients treated with construct A and construct B were 86% and 93%, respectively, and a significant difference was found (*P* = .043). The Constant scores in construct A were 72.4 (SD, 13.6); section A: 12.1; section B: 14.9; section C: 34.1; and section D: 11.3. The mean Constant scores in construct B were 79.9 (SD, 10.5); section A: 13.7; section B: 16.1; section C: 37.2; and section D: 12.9. The difference was due to the range of motion subgroup (*P* = .017). The mean irCS according to the different construct, sex, and age is reported in Table I. No significant difference was found between the irCS at 12 months postoperatively and at the final follow-up in all patients.

As assessed by the VAS (0, no pain; 10, worst pain possible), 46 patients (88%) rated their pain as 0 of 10. Pain was

Table I Mean individual relative Constant-Murley Score according to the construct type, sex, and age

Variable	irCS	*P* value
Construct A	86.47 (11.25)	**.043**
Construct B	92.82 (6.21)	
Sex		>.05
Male	90.66 (7.98)	
Female	90.72 (8.04)	
Age, yr		
<60	90.56 (8.10)	>.05
≥60	90.77 (9.01)	

irCS, individual relative Constant-Murley Score.
Data are presented as mean (standard deviation).
Bold indicates statistically significant *P* value ($P < .05$).

rated as 1 of 10 in 4 patients (8%) and as 2 of 10 in 2 patients (4%).

According to the Bahrs criteria, the postoperative reduction was considered excellent in 97% of patients and good in the remaining 3% and was classified at the final follow-up as excellent in 89% and good in 11%. In particular, the mean postoperative and final neck shaft angles were 135° (construct A: 134.7°, construct B: 135.1°) and 132.9° (construct A: 131.3°, construct B: 133.8°). A significant difference ($P = .047$) was found between the 2 constructs according to the variation of neck shaft angle.

No signs of arthritis were seen in the study group during the follow-up.

Discussion

The incidence of displaced 3-part proximal humeral fractures is growing, particularly in the elderly population,[15] so that the treatment of these fractures daily represents a challenge for shoulder surgeons.

We are presenting the results of a consecutive series of patients with 3-part proximal humeral fractures, involving the surgical neck and the greater tuberosity, surgically treated with blocked threaded wires (Galaxy) in 2 different fixation constructs.

In our groups, the rate of major complications was 2%. Literature indicates that the percentage of complications after plate fixation of proximal humeral fractures is considerable.[7,10,11,14] In particular, Gumina et al[7] observed 9.6% complications in a series of Hertel 7 fractures treated with 2 different locking plates. The low incidence of complications with the blocked threaded wires is probably due to minimally invasive reduction maneuvers and percutaneous fixation, which do not further compromise humeral head perfusion. Furthermore, this surgical choice does not involve (1) periosteal or (2) fracture hematoma removal, (3) the humeral head does not undergo perforations, and in addition, (4) the earlier removal of the fixation device can facilitate bone healing.

A low rate of infections was found, despite the use of a percutaneous pinning. In our series, we observed only 2 superficial infections, and both resolved after 5 days of oral antibiotics. The mandatory weekly antiseptic treatment of the inlet holes and the short duration of surgery are 2 possible explanations of this low incidence.

The well-known complications consequent to percutaneous pinning are represented by migration of the wires in the postoperative phase and the progressive loss of intraoperative fracture reduction.[4] Therefore, this surgical technique is mainly reserved for low-demand patients at American Society of Anesthesiologists Physical Status Classification III and IV.

In our series, a device composed of threaded wires blocked by clamps and a bar was used. This configuration ensures no pin migration and reduction maintenance for the postoperative period, making this fixation choice useful also in a high-demand population. The irCS in our series was 89%. The value is superimposable or slightly higher than series where 3-part humeral head fractures were treated with other fixation devices.[7,10,11,14]

Excellent clinical results were observed for the 2 fixation constructs in all the 4 subcategories of the CS, confirming that construct A and B are both valid configurations for the use of the system. However, patients treated with the construct B, in which an additional couple of threaded wires were used, reached significantly higher values of irCS. The difference was due to the "range of motion" subcategory.

This biomechanical difference between the 2 constructs is confirmed by the radiologic and clinical outcomes observed in our series; in fact, a significant difference in the neck-shaft angle between the intraoperative reduction and the final follow-up was observed in patients treated with the 2 different fixation constructs. The intraoperative reduction was maintained in almost all patients treated with construct B, allowing an excellent recovery of the range of motion.

This study has some limitations. The midterm follow-up does not allow identification of long-term complications. Another limitation is the relatively low number of patients, although the studied group was composed of patients with the most frequent pattern of 3-part humeral head fracture.

Conclusion

In the absence of complications, the functional and radiologic results obtained after treatment of 3-part proximal humeral fractures with percutaneous fixation or locking plates are similar; however, the percentage of major complications after percutaneous treatment is lower. Results of percutaneous fixation depend on the biomechanical construct.

Disclaimer

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