Injury, Int. J. Care Injured 48S3 (2017) S12–S19

Contents lists available at ScienceDirect

Injury

journal homepage: www. elsevier.com/locate/Injury

Triangular block bridge method for surgical treatment of complex proximal humeral fractures: theoretical concept, surgical technique and clinical results

Raffaele Russo[a,*], Daniela D'Auria[b], Michele Ciccarelli[a], Giuseppe Della Rotonda[a], Gesualdo D'Elia[c], Bruno Siciliano[b]

[a]Orthopedic Department, ASL Naples 1 "Pellegrini Hospital, 41 Portamedina Street, 80135 Naples, Italy
[b]PRISMA Lab, Electrical Engineering and Information of Technology Department, Federico II University, 21 Claudio Street, 80125 Naples, Italy
[c]Radiology Department, ASL Naples 1 "Pellegrini Hospital, 41 Portamedina Street, 80135 Naples, Italy

KEYWORDS

Proximal humeral fracture
Triangular block bridge
Isostatic structure
da Vinci system
Synthesis

ABSTRACT

Introduction: Criteria for classification, indication and choice of a surgical device to treat proximal humeral fractures are still controversial. We report an original technique based on a mechanical concept with a structural principle of a triangle as a rigid body applied to the humeral head fractures in association with other devices. This retrospective study aims to describe in detail the surgical technique and results at long time follow up.

Methods and Material: We analysed two series of 101 patients with proximal humeral fractures (mean age, 52.9 y; range 19–78 y) treated between 2001 and 2012 reporting the clinical and radiological results. In the first series of 23 cases (mean age 51.4 y, range 35–74 y) we used as support a bone piece taken from allograft or autologous tricortical iliac crest and shaped as a triangular pyramid during the operation; while in the second series of 78 cases (mean age 53.6 years, range 29–78 years, SD 13.5 years) a triangular titanium cage was used in 69 patients while in 9 allograft or bone substitute was used as augmentation. An analytical retrospective study was done to understand the mechanical function of medial augmentation composed by a solid body in association with different types of synthesis to stabilize properly a proximal humeral fracture.

Results: We obtained excellent and good results in 83,2% of patients, fair in 12,8% and bad in 4% in terms of active anterior elevation, external and internal rotation, pain and strength according to Constant and DASH score.

Conclusion: A medial solid body, especially in titanium material and shaped as trapezoidal/pyramidal form used to fill the secondary bone loss in complex instable proximal humeral fracture, allows an anatomic reduction and stable fixation in association with simple and more complex tools and it provides a better biomechanical environment for union and maintenance of alignment.

Introduction

Minimally displaced proximal humeral fractures can be conservatively treated while the displaced ones often need a surgical treatment with an increasing number of these patients in the last years [1]. The management of these injuries is still controversial especially for classification, indication and patients' age [2–4].

In the Literature there are no techniques and devices that give better results than the others [3–7]. In the last years the use of locked plates is increased with different complications reported such as the loss of reduction, joint violation for screws penetration and the high number of cut-out with raising percentage of reoperations [4]. The purpose of this study is to report clinical and radiographic results after open reduction and internal fixation of proximal humeral fractures with the Triangular Block-bridge method [7]. We used this technique since 2001 with a pyramidal bone graft (handcrafted from allograft or iliac crest bone) as medial or internal augmentation associated with minimal osteosynthesis. In 2005 the tool was changed for a titanium triangular prism (Da Vinci system) [8] in 5 different sizes (Arthrex Naples Florida) in combination with non-absorbable osteosutures and minimal osteosynthesis such as cannulated screws or K-wires, and a small low-profile plate (Depuy Synthes) with minimal osteosynthesis. We describe some theoretical aspects of this method, the surgical technique and report the clinical results in 101 patients.

* Corresponding author at: Raffaele Russo, MD. Ospedale dei Pellegrini, Via Portamedina alla Pignasecca 41, 80135 Napoli, Italy.
E-mail address: raffrusso@tin.it (Raffaele Russo).

0020-1383 / © 2017 Elsevier Ltd. All rights reserved.

Physical and mechanical device principles

The triangular shape of da Vinci system (Figure 1) has been developed for the necessity to have a versatile support in order to stabilize as much as possible a displaced humeral head with two, three or four parts.

The current classification as described by Neer and after from AO foundation in two, three and four parts with subgroups could be not enough to describe the patho mechanical patterns of proximal humeral fracture [9] due to the complex aspects of some of them especially when there is a comminution of medial hinge. For this reason, we have developed a new CT scan assessment of broken medial column [8], useful also for the interpretation of all types of fractures from 2 to 4 part. We evaluated the calcar region in the patho-mechanics analysis of fractures not as a linear structure but as a three-dimensional one based on a 3D CT-scan model. Moreover, according to his displacement in axial, coronal and sagittal planes of the space we can evaluate the degree of complexity from a 2 part to four-part fracture patterns. In all cases, from the simplest to the most complex humeral proximal fracture, a solid biocompatible body with triangular shape was used and put into medullary cavity and allowed the stable distribution of rotator cuff and deltoid compressive forces due to an adequate fracture support with a limitation of torsional forces. Our device is very similar to an extruded triangle (Figure 2) that respects the condition of an isostatic structure. More specifically, the system follows the isostatic equivalence:

$$a = (2 \times n) - 3$$

where a is the rod and n is the node of the structure. In our case, $a = 9$ and $n = 6$, and thus the equivalence is satisfied. Furthermore, the device scarce depth has a negligible impact on its mechanical properties. Consequently, the overall system can be modeled as a structure composed by three rods hinged among them in a triangle. Thus, the prototype behavior can be assumed like a rigid body. As a matter of fact, in consideration that the angular momentum of the three conceptual rods must be the same, their triangular chain behaves only like a stiff body. If at this solid "bridge" inside the medullary canal, are added tension band outside from the cuff to the cortical bone of the diaphysis and external pins crossing the triangular structure from the diaphyseal cortex to inside, according to neck-shaft angle, it transforms into a stable system allowing the minimum bearing loads due to normal muscle tone and movement during the rehabilitation process. This system represents the mechanical concept of the non-deformable triangle as an inclined arrangement and it opposes horizontal to vertical stresses in compression and torsion thereby avoiding varus deformity and retroversion of the humeral head. Moreover, the neck-shaft angle can be stabilized by metal supports placed from the top to the bottom of the fracture; in addition, bending and torsional moments are reduced by external tie rods. Eventually, in order to prevent the deformity, our triangular structure opposes to varus torsional forces because of its geometric shape. In addition, it promotes healing as the fragments are stable and loss of reduction is prevented.

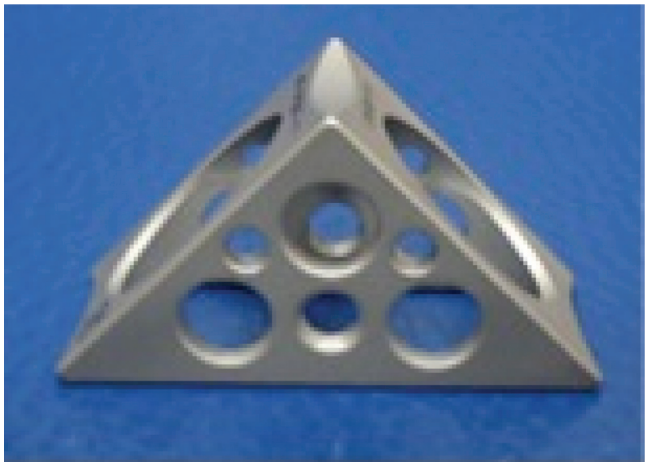

Fig. 1. Da Vinci system.

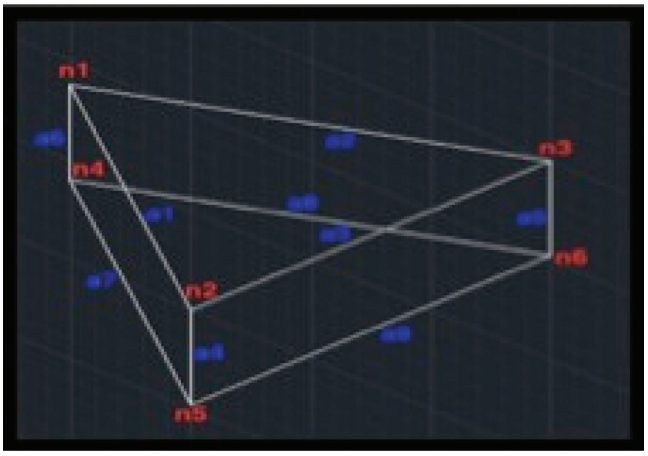

Fig. 2. Da Vinci system design.

Subjects and methods

This study was based on a retrospective case control analysis on 101 patients (65 right arm, 35 left arm, 1 bilateral) with mean age of 52.4 y (19–78 years) treated for complex humeral fractures between 2001 and 2012. All investigations were conducted in conformity with ethical principles of research and for this type of study. The inclusion criteria were acute, traumatic two-part, three-part and four-part fracture patterns according to Neer classification [10]. At the beginning in the first group there were 33 patients (20 men, 13 women; 21 right arm, 2 left arm) with a mean age of 56 years (range 34–74 years) and the fractures were classified as 6 displaced 3-part fractures, 12 displaced 4-part fractures, 8 anterior 4-part fracture-dislocations, and 7 comminuted [7]. Of this group we reviewed 23 patients (3 died and 7 lost at follow-up) at mean 77 months follow-up (range 84 to 156 months) with a mean age of 51.4 years (range 35–74 years; 15 men, 5 women, 18 right side, 5 left side) with 5 displaced 3-part fractures, 10 displaced 4-part fractures, 5 anterior 4-part fracture-dislocations and 3 comminuted. In the second group we reviewed 78 patients (79 shoulders; 45 men and 33 women; mean age 58.3 years; range 19–78 years; 48 right and 31 left shoulders) at mean 72 months follow up (range 12–132 months) with 2–3 – or 4-part fractures, fracture-dislocations, or unclassifiable complex fractures of the proximal humerus. The fractures were classified in 9 patients as 2-part, in 23 as 3-part, in 22 as 4-part fracture, in 15 as fracture-dislocation, or unclassifiable fracture in 10 cases.

Patients were examined at follow-up according to Constant-Murley score [11] and the Disabilities of the Arm Shoulder and Hand score to evaluate the function. At x-ray control the fractures healing were evaluated with radiographic union score and clinical evaluation [12] (malunion, avascular necrosis, varus and valgus alignment and development of post-traumatic osteoarthritis). Humeral head alignment was considered normal with a deviation in all planes from 0° up to 10°. In the first group of patients, between 2001 and 2005, the technique used was an open reduction and medial endo-osteal augmentation with autologous tricortical bone harvested from the iliac crest (more rarely) or dry bone bank block shaped as triangular trapezoidal block. In the second group, treated between 2005 and 2012, 9 shoulders were managed using allograft or bone substitute,

while the other 70 were treated with titanium triangular shaped implant, minimal osteo-synthesis (K wires, osteosutures and/or thin and elastic non-locked or locked plates) with a preference of minimal osteosynthesis in case of multifragmentary great tuberosity. In the first group the k-wires were percutaneous and removed systematically at 30 days from surgery, while in second one were put during the open procedure and cut close to the bone.

Surgical technique

All surgeries were performed under general anaesthesia or interscalene block or both. Fluoroscopy control of the fracture was carried out before and during the operation. The use of delto-pectoral approach is mandatory for this surgery. The cephalic vein was dissected laterally and generally bound; then, the deltoid and pectoralis major were carefully separated. A retractor was placed between the deltoid and pectoralis major, and the clavi-pectoralis fascia was dissected to allow evacuation of the fracture hematoma. The subacromial bursa was removed and the sub deltoid space was opened with a Browne retractor. The conjoint tendon was retracted medially, the subscapularis muscle was exposed. Fracture reduction and stabilization with the triangular block bridge is influenced by whether a two-part, three-part or four-part fracture is present.

Two-part fracture

The fracture pattern is identified and the internal part of humeral head is exposed by traction and extending the arm. The weak trabecular bone at the center of the head is reinforced with the bone block or titanium cage. Based on trial a proper size of the Da Vinci System is chosen. The structure is reinforced by tension band wiring which passes proximally from the rotator cuff at the bone tendon junction and distally through holes drilled in the diaphysis. Cannulated screws or pins are then passed from the diaphysis into the proximal head fragment either beneath or through the wedge shaped cage. In case of comminuted calcar an additional lateral cortical plate is used for stability (Figure 3).

Three-part fracture

The management of this fracture pattern is more complex and depends on it characteristics. The greater tuberosity is fixed with *n*°2 non-absorbable suture passed through rotator cuff and bone junction. The cavity under the head is filled with the cage. We reattach the greater tuberosity to the head and diaphysis using osteosutures placed before fixing this area with K-wires and stabilize the great tuberosity with other trans-osseous sutures or cannulated titanium screws. The final step is to reinforce the stabilization achieved with *n*°2 non-absorbable osteo-sutures through the great tuberosity and the diaphysis or the head and the diaphysis. If necessary locking or not locking plate was used (Figure 4).

Impacted valgus and varus four-part fractures

The management of 4-part fracture is very complex especially in elderly people. The first surgical step in valgus fractures is to reduce the humeral head in anatomical position and then to fill the meta epiphyseal space with a cage of appropriate size that is temporarily fixed to the head and diaphysis with one or two 1.8 mm K-wires drilling from the latero-distal cortical bone. At this point we mark the great and lesser tuberosities using non-absorbable *n*°2 sutures passed through their respective tendons and pull both in order to reduce the fracture fragments anatomically around the cage. An intraoperative x-ray control is done to check the reconstruction made and the final step is to stabilize with screws and locking or not locking plates (Figure 5).

In a 4-part varus fracture the most important and difficult step is to identify how the calcar is involved in the fracture. Once the calcar fracture is well recognized the Da Vinci System cage is inserted into

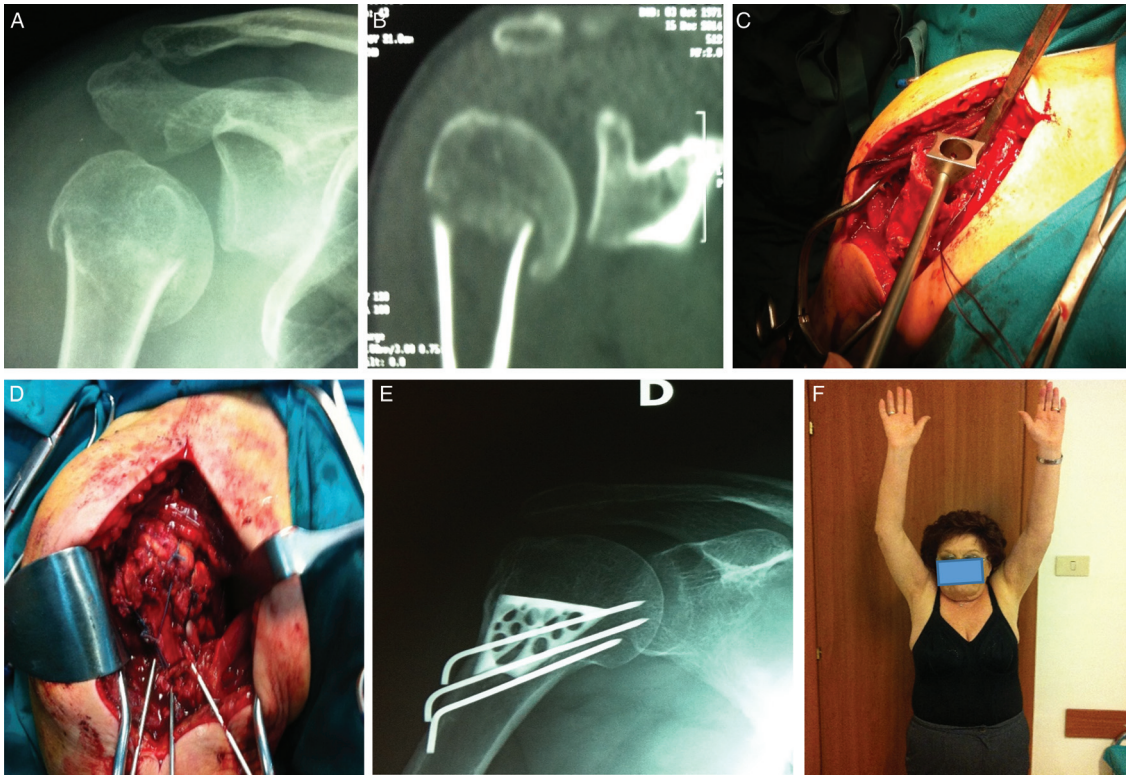

Fig. 3. Two part fracture. (A) X-ray (B) CT- scan (C) Cage measurement (D) Final fracture stabilization (E) 5-years x-ray control (F) 7-years clinical control.

Fig. 4. Three-part fracture. (A) X-Ray in internal rotation (B) CT- scan (Sagittal View) (C) CT- scan (D) Intraoperative bone loss (E) Da Vinci system in situ (F) Intraoperative x-ray control (G) 6-months x-ray control (H) 4 years clinical control.

diaphyseal canal in order to give the appropriate support for the anatomical reorientation of the head. Once the humeral head-calcar ratio (the fracture complexity in the median area under the head) is well established, the tuberosities can be reconstructed around the endosteal materials. The other steps are the same described for the 4 part valgus fractures (Figure 6).

Postoperative protocol

The arm was placed in a sling with the shoulder in adduction and elbow at 90° of flexion. The time of immobilization was variable according to the type of fracture and osteosynthesis done; generally 2–3 weeks for a two-part fracture and 4 weeks for 4 parts. After the immobilisation the patient starts the rehabilitation in water (Lionnese Protocol) [13] for a mean period of 10 weeks, 3 times per week with one-hour session. Home exercises are done by patients 3 times per week for 1 hour. We see patients in our office every 4 weeks and take an x-ray control at 4 weeks after surgery to start the rehabilitation, at 3 months, 6 months and one year.

Results

A total of 101 patients were followed up for an average of 72 months (range 12–132 months). There were no intraoperative or postoperative neurovascular or nerve injuries or sub acromial hardware impingement. We observed either radiologically and clinically a fracture healing at a mean time of 4 months after surgery [12]. All patients had a radiographic protocol of control after surgery at one month, three, six months and one year. In case of complex fractures we performed a CT-scan exam at six months, one year and two years. We had no infection in the first group of our series whereas in the second group we noticed one superficial infection treated with antibiotic specific therapy and a deep infection treated successfully with surgical removal of the infected and necrotic head and a cement spacer implantation.

In all patients of the first group the fracture healed with restoration of humeral head alignment close to normal. In 18 (78.2%) of them, we found an anatomical reconstruction with restoration of neck shaft angle. In all 23 patients we not found a glenohumeral joint osteoarthrosis (Figure 7).

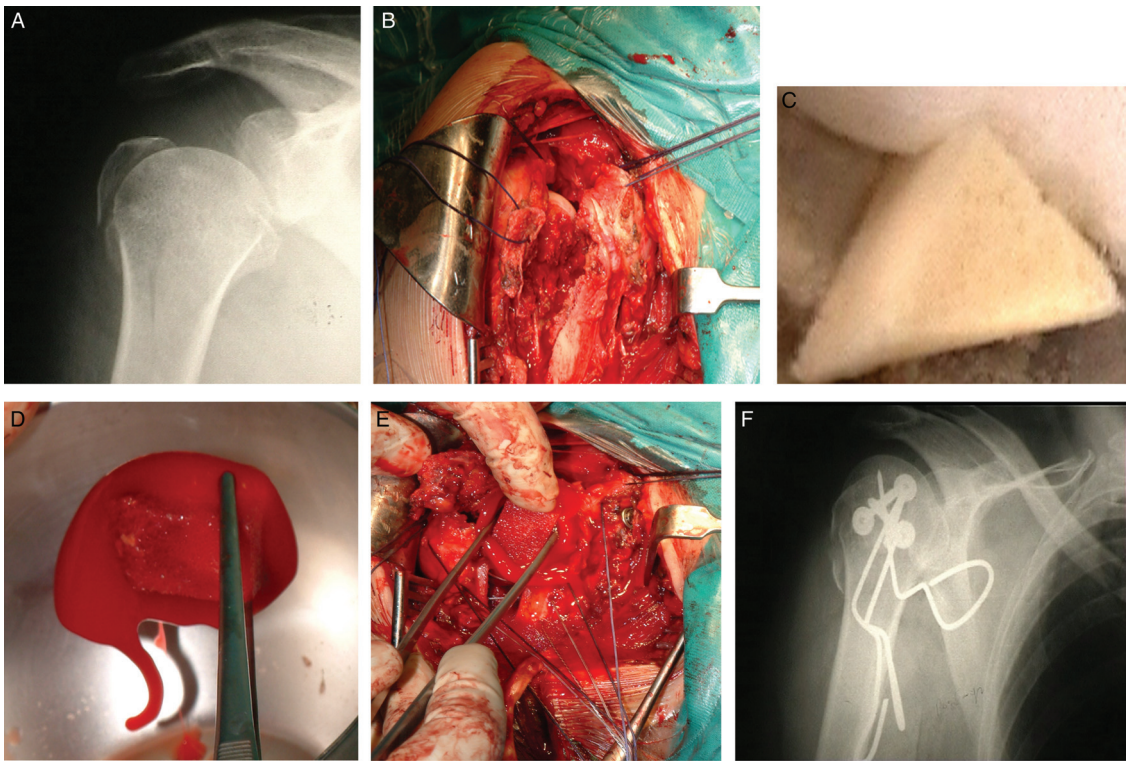

Fig. 5. Valgus fracture. (A) Preoperative x-ray (B) Intraoperative bone loss (C) Triangular shaped bone block (D) The allograft in blood (E) Bone block in situ (F) postoperative x-ray control.

Analysing the patients' X-rays and CT scan we observed two cases (8.6%) of avascular necrosis, one was symptomatic and treated with prosthesis, and three cases (13%) complicated by secondary inferior osteophytes with no necessity of replacement. The mean final Constant score decreased from 80.25 to 77.8 with an average active anterior elevation of 150° and the Dash score was 51. In the second group of 78 patients (79 shoulders), 69 shoulders were treated with the da Vinci system and 10 with allograft or substitute bone-block technique [14] and all cases were stabilized with minimal osteosynthesis or hybrid with thin plates or locked plates [15]. In this group of patients, we did not observe any important axial mal-rotation and in 65 of cases (82.2%), some of which were very complex, we performed an anatomical reconstruction. We observed varus displacement (10°) only in two cases (2.5%) and tuberosity mal-alignment in one and the results were excellent in 37 cases (46.8%), good in 27 (34.1%), fair in 10 (12.6%) and bad in 5 (6.3%) with mean active anterior elevation of 160° in excellent or good cases.

We removed in 15 cases (18.9%) out of 79 the k-wires under local anesthesia due to their joint migration or a local bone reabsorption especially in patients older than 70 years with no pain in 10, while symptomatic in 5 (Figure 8); consequently, after the definitive bone fixation, all k-wires were removed (Figure 9).

In all 102 shoulders we obtained excellent and good results in 83.2%, fair in 12,8% and bad in 4%; 49 (48%) patients reached T7 in internal rotation, 28 (27.4%) could reach T12, 12 (11.7%) reached the lumbar spine and 13 (12.7%) reached his buttock. In any case we observed cut-out of screws.

Radiological results

All the patients had and x-ray control and 33 had a CT scan. The fracture was healed in 99 out of 101 patients. In the first series we observed 7 cases (30.4%) with radiological displacement of greater and lesser tuberosities less than 5 mm and in 8 (34.7%) patients we observed a minimal bone loss area under the humeral head with displacement and penetration for few millimetres of k-wires in the joint but pain free in patients before 30th days from surgery (the correct time in our first protocol to remove all pins); secondary minimal osteosclerosis at longer follow-up was observed in 9 patients (39%). In the second series of patients we observed one case that healed with 20° of the head in varus with broken of plate but with good shoulder function at 150° of elevation. In one case we observed a secondary greater tuberosity migration of 1.5 cm with limitation of external rotation of 35°. In 4 cases (5%) there was a secondary para-articular ossifications reabsorbed spontaneously in two cases. In 5 cases (6.3%) we observed a focal condral osteosclerosis with loss of motion of 30° between 5 years and 7 years from the operation. Two important cases of osteoarthritis (2.5%) of the humeral head were observed, but only one was treated with replacement.

Generally, after the all types of synthesis, due to torsional forces, some fragment displacements were observed; in all 102 shoulders the number of secondary displacement was minimal not more than 3 mm.

Discussion

The surgical management of the proximal humeral fracture is still considered a challenge and there is no agreement on the treatment especially in terms of indications, surgical approach and devices to choose [16,17]. No technical devices so far, from minimal invasive to open surgery, gave better results than the other due to the difficulties to obtain an anatomic reduction, stable fixation and very good bone healing [18–22]. In the Literature surgical failures between 20% and 40% and revision surgery rates of up to 25% are reported also with the last generation of locking plates [9,10,23]. The complication of head necrosis still represents an unsolved problem with either open or percutaneous techniques with a percentage between 9% and 75% [12,20,24]. Anatomic and reverse prostheses have been associated with a large number of complications and unsatisfactory outcomes especially in terms of shoulder function [25].

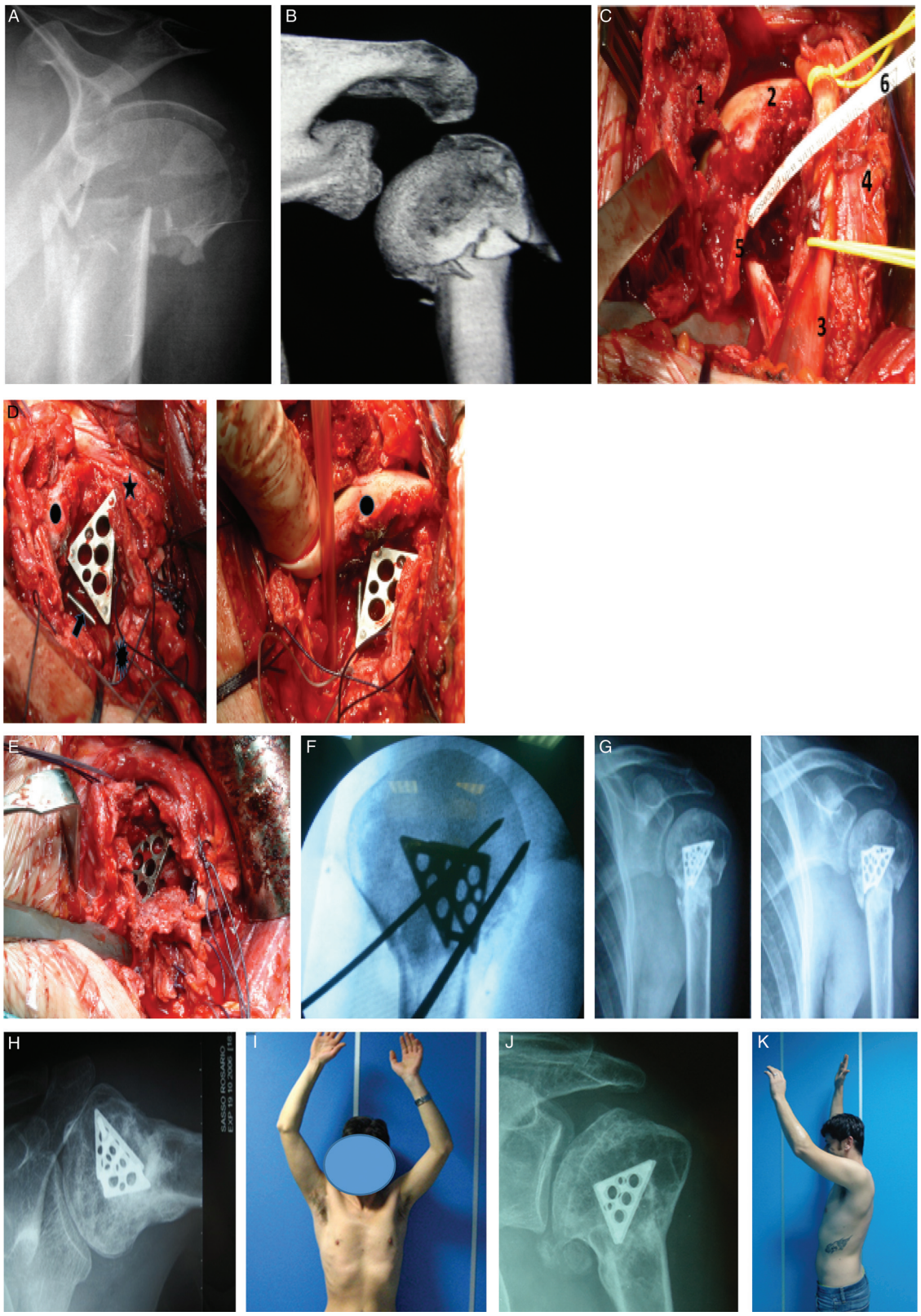

Fig. 6. Varus fracture. (A) X-ray (B) CT- scan (C) Intraoperative bone loss (D) Cage inside and head correction (E) Cage and osteosutures (F) Intraoperative x-ray (G) 7 months x-ray control (H) 2 y x-ray control (I) 2 y clinical control (J) 7 y x-ray control (K) 7 y clinical control.

We believe that an accurate CT- scan evaluation of concomitant medial hinge fracture associated with the other fragments is important for the prognosis and surgical treatment of all proximal type from 2 to 4 parts [8]. A preoperative planning of the medial calcar reconstruction is crucial for good outcomes in all surgical techniques. In 2008 we described a technique called the "block-bridge" [7] based on a reconstruction of the humeral proximal part around a triangular bone placed into the epiphyseal canal and we reported very good

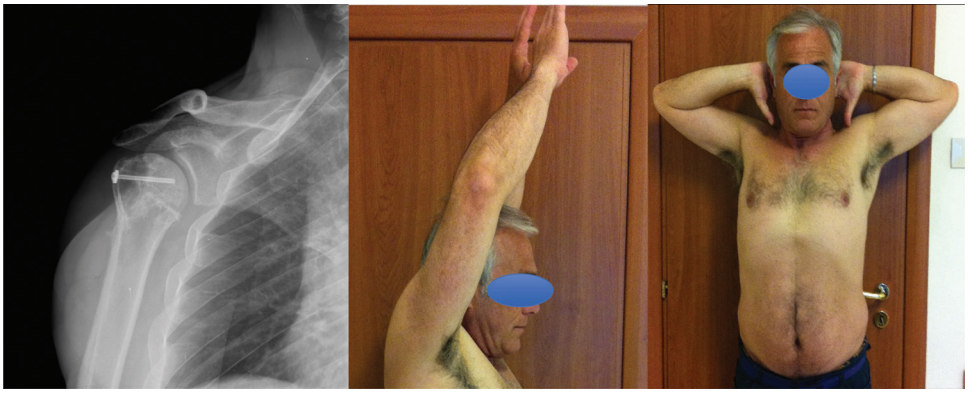

Fig. 7. 13 years x-ray and clinical control.

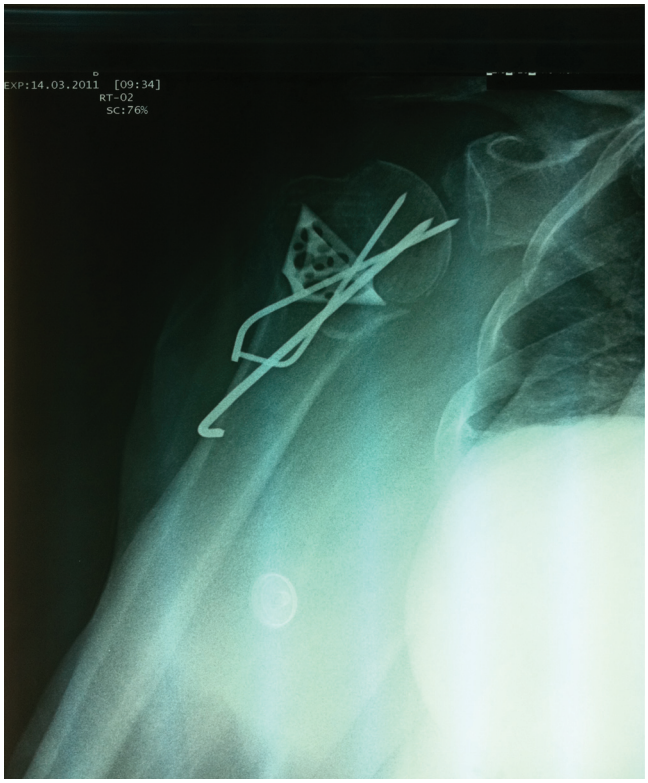

Fig. 8. K-wires displacement.

results despite the fractures complexity. In 2012 we reported a series of 69 patients treated with a new device, as evolution of triangular bone handcrafted from iliac crest or often from the bone allograft, called “da Vinci system” [14], with very low rate of complications. The main principle of this new system is the eased possibility to the surgeon to reach a good reconstruction of the medial calcar fractured, to fill the bone defect and provide a stable osteosynthesis with his insertion between head, diaphysis and lesser and great tuberosities. This particular technique of internal augmentation might be very useful to treat displaced proximal humeral fractures that we used in 101 patients and in our opinion it is an interesting innovation based on mechanical capacity, as demonstrated by theoretical evaluations and clinical and radiographic results to treat difficult cases with low percentage of complications. The “da Vinci” system can be considered as an evolution of the bone block technique to increase the mechanical aspect of stability such as fracture with metaphyseal bone loss, to increase the proximal humeral re-vascularization and healing due to the stable effect of association between medial support and lateral synthesis. In our series we observed a low percentage of main complications: two infections in patients aged more than 75 years; we removed the cage, 80 days after surgery, in one case while the other one was solved with antibiotic therapy for 6 months. Two prosthesis were implanted for a secondary osteoarthritis. K-wires removal was necessary in 15 cases due to their joint migration or for pain during shoulder function, but using minimal surgical approach and local anesthesia. However, in our series we had a higher rate of good clinical results in a percentage more than 85% of cases that represents a rate superior to the reported results of humeral prosthesis and all other devices, especially regarding the locked plates. This study has several limitations. Our group is not homogeneous in terms of age and type of fractures, there is no control group and it is a retrospective series

Fig. 9. X-ray before and immediately after k-wires removal.

control. A longer follow up on a greater number of patients is necessary to better understand the results of this augmentation technique and identify long-term complications such as avascular necrosis and the development of osteoarthritis.

Conclusions

Our innovative device has a triangular shape and respects the condition of an isostatic structure. Moreover, this rigid body promotes the surgical ability to reconstruct all types of proximal humeral fractures, particularly when complex due to comminution and displacement of the medial hinge segment. The results of this study show that the use of our system as internal-medial support allows an easier reduction and a stable fixation in the treatment of displaced proximal humeral fractures, even when the head is dislocated and the fracture is multi-fragmentary. The triangular bridge located under the head is important to support the head and the tuberosities in order to allow minimal osteosynthesis and to facilitate revascularisation.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgement

A great acknowledgement to all the patients of the Ospedale dei Pellegrini who have been involved in the experiments.

References

[1] Darder A, Darder A, Jr, Sanchis V, Gastaldi E, Gomar F. Four-part displaced proximal humeral fractures: operative treatment using Kirschner wires and a tension band. J Orthop Trauma 1993;7:497–505.
[2] Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury 2006; 36:691–7.
[3] Anjum SN, Butt MS. Treatment of comminuted proximal humerus fractures with shoulder hemiarthroplasty in elderly patients. Acta Orthop Belg 2005 Aug;71:388–95.
[4] Rockwood CA, Matsen FA. The shoulder. Philadelphia: Saunders Company; 1998.
[5] Demirhan M, Kilicoglu O, Altinel L, Eralp L, Akalin Y. Prognostic factors in prosthetic replacement for acute proximal humerus fractures. J Orthop Trauma 2003;17:181–8.
[6] Russo R, Lombardi LV, Ciccarelli M, Giudice G, Cautiero F. A new osteosynthesis device for the treatment of proximal humerus fractures. Description of the technique and preliminary results. Chir Org Mov 2008 Jan;91:27–34.
[7] Russo R, Visconti V, Vernaglia Lombardi L, Ciccarelli M, Giudice G. The block-bridge system: a new concept and surgical technique to reconstruct articular surfaces and tuberosities in complex proximal humeral fractures. J Shoulder Elbow Surg 2008 Jan-Feb;17:29–36.
[8] Russo R, Cautiero F, Della Rotonda G. The classification of complex 4-part humeral fractures revisited: the missing fifth fragment and indications for surgery. Musculoskelet Surg 2012 May; 96(Suppl 1):S13–19. doi: 10.1007/s12306-012-0195-2. Epub 2012 Apr 19.
[9] Jost B, Spross C, Grehn H, Geber C. Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome. J Shoulder Elbow Surg 2013 Apr;22:542–9.
[10] Neer CS, II. Displaced proximal humerus fractures: II. Treatment of three-part and four-part displacement. J Bone Joint Surg 1970;52A:1090–103.
[11] Angst F, Hans-Kaspar S, Beat R. Measures of adult shoulder function Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH) and its short version (QuickDASH), Shoulder Pain and Disability Index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society Standardized Shoulder Assessment Form, Constant (Murley) Score (CS), Simple Shoulder Test (SST), Oxford Shoulder Score (OSS), Shoulder Disability Questionnaire (SDQ), and Western Ontario Shoulder Instability Index (WOSI). Arthritis Care & Research November 2011;63(S11), pp. S174–88. doi: 10.1002/acr.20630 2011. American College of Rheumatology.
[12] Morshed S. Current options for determining fracture union. Adv Med 2014;2014:708574. doi: 10.1155/2014/708574. Epub 2014 Sep 14.
[13] Liotard JP, Edwards TB, Padey A, Walch G, Boulahia A. Hydrotherapy rehabilitation after shoulder surgery. Tech Shoulder Elbow Surg 2003;4:44–9.
[14] Russo R, Visconti V, Lombardi L.V, Ciccarelli M, Cautiero F. Da Vinci system: clinical experience with complex proximal humerus fractures. Musculoskeletal Surg 2010;94:75–64, ISSN:2035-5106.
[15] Russo R, Cautiero F, Ciccarelli M, Vernaglia Lombardi L. Reconstruction of unstable, complex proximal humeral fractures with the da Vinci cage: surgical technique and outcome at 2–6 years. J Shoulder Elbow Surg 2013 Mar;22:422–31.
[16] Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. Results of operative treatment. J Bone Joint Surg Am 2003;85:1647–55.
[17] Bigliani LU, Flatow FL, Pollock PG. Proximal humeral fractures. In: Rockwood CA, Jr, Matsen FA, III, editors. The shoulder. Phildelphia: Saunders; 1998. pp. 327–78.
[18] Keener JD, Parson BO, Flatow EL, Rogers K, Williams GR, Galatz LM. Outcomes after percutaneous reduction and fixation of proximal humerus fractures. J Shoulder Elbow Surg 2007 May-Jun;16:330–8.
[19] Hertel R. Fractures of the proximal humerus in osteoporotic bone. Osteoporos Int 2005;16 (Suppl 2):S65–72.
[20] Brunner F, Sommer C, Bahrs C, Heuwinkel R, Hafner C, Rillmann P, et al. Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. J Orthop Trauma 2009;23:163–72.
[21] Kruijf M De, Vroemen JP, de Leur K, van der Voort EA, Vos DI, Van der Laan L. Proximal fractures of the humerus in patients older than 75 years of age: should we consider operative treatment? J Orthop Traumatol 2014 Jun;15:111–15. PubMed PMID: 24233865; PubMed Central PMCID: PMC4033798.
[22] Wong J, Newman JM, Gruson KI. Outcomes of intramedullary nailing for acute proximal humerus fractures: a systematic review. J Orthop Traumatol 2016 Jun;17:113–22. doi: 10.1007/s10195-015-0384-5. Review. PubMed PMID: 26507521; PubMed Central PMCID:PMC4882300.
[23] Gerber C, Spross C, Grehn H, Jost B. Complications after locking plate fixation of fractures of the proximal humerus. Presented at the 2011 Congress of the Société Européenne de Chirurgie de l'Epaule et du Coude, Lyon, September 2011.
[24] Resch H, Hubner C, Schwaiger R. Minimally invasive reduction and osteosynthesis of articular fractures of the humeral head. Injury 2001;32(Suppl 1):SA25–32.
[25] Reitman RD, Kerzhner E. Reverse shoulder arthroplasty as treatment for comminuted proximal humeral fractures in elderly patients. Am J Orthop (Belle Mead NJ) 2011 Sep;40:458–61.