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Valgus impacted proximal humeral fractures and their blood supply after transosseous suturing

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Abstract We treated 16 patients (11 women and five men, average age 45 years), all having four-part valgus impacted fractures of the proximal humerus, with transosseous suturing. All had preoperative angiography performed 6–12 h after admission. The average impaction angle was 43°, and the mean lateral displacement of the humeral head was 1.4 mm. Postoperative angiography was performed 8–10 weeks after the operation followed by digital image processing using the segmentation technique. No statistically important reduction in the length and area of large (>0.5 mm) vessels was seen. Union was confirmed by the reduction in the length and area of small vessels (<0.5 mm). At a mean follow-up of 40 months, avascular necrosis was only found in one patient. The average Constant–Murley score was 87 (67–100) points, whereas the functional score in comparison with the unaffected shoulder was 94% (89–100%). Despite the small number of patients, transosseous fixation seems to preserve the remaining blood supply of the humeral head.

Résumé Nous avons traité 16 malades (11 femmes et 5 hommes, d'âge moyen 45 ans), présentant une fracture de l'humérus proximal à 4 fragments, impactée en valgus, avec suture trans-osseuse. Tous avaient une angiographie préopératoire exécutée 6 à 12 heures après l'admission. L'angle moyen de l'impaction était 43° et le déplacement latéral moyen de la tête humérale 1.4 mm. L'angiographie postopératoire a été exécutée 8–10 semaines après l'opération, en utilisant la technique de la segmentation. Aucune réduction statistiquement importante dans la longueur et le territoire des vaisseaux de plus de 0.5 mm n'a été noté. L'union a été confirmée par la réduction de la longueur et du territoire des petits vaisseaux (<0.5 mm). À un suivi moyen de 40 mois, une seule nécrose avasculaire a été trouvé. Le score de Murley Constant moyen était 87 (67–100) points alors que le score fonctionnel en comparaison de l'épaule non affectée était 94% (89–100%). En dépit du petit nombre de malades étudiés, la fixation trans-osseuse paraît conserver la vascularisation restante de la tête humérale.

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Introduction

The four-part valgus impacted fracture was first reported in 1991 by Jacob et al. [12]. It was considered a subtype of proximal humeral fractures, and it accounts for approximately 14% of all humeral head fractures. The articular fragment is impacted into the metaphysis separating the greater and lesser tuberosities and producing a fracture line through the anatomical neck with minimal or no lateral displacement of the head. In 2002, Neer [15] updated his four-segment classification of proximal humeral fractures and included the four-part valgus impacted fracture as a borderline lesion (type A) in the continuum of lateral displacement of the head that progresses from those with minimal displacement to the valgus impacted type and then on to the true four-part fracture (lateral fracture-dislocation, type B).

The reported incidence of avascular necrosis (AVN) in this type of fracture after minimally invasive techniques of fixation is low [10, 12, 17–19, 22], because the medial hinge of the periosteum is usually preserved. This is especially true when there is either only minimal or no lateral displacement of the head [12, 17, 18].

Materials and methods

Between April 2000 and May 2001, 16 consecutive patients with an acute four-part valgus impacted fracture of the proximal humerus underwent open reduction and internal fixation. There were 11 women and five men with an average age of 45 (33–61) years at the time of injury. Initial anteroposterior radiographs were used to measure both the impaction angle between the fracture plane of the articular segment and the axis of the humeral shaft and any displacement of the humeral head (Fig. 1). The mean angle of impaction was 42° (range: 37–48°), the lateral displacement of the head was between 0 and 7 mm (mean 1 mm), and the anteroposterior displacement was less than 1 cm. Anteroposterior and axillary radiographs were obtained at the final follow-up (40 months, with a range of 36–46 months) and used to assess fracture position, any posttraumatic osteoarthritis, AVN, and nonunion. The functional outcome was assessed with the Constant and Murley scoring system.

Surgical technique and rehabilitation

Using an anterolateral transdeltoid approach, the fracture line between the tuberosity fragments is identified and gently separated in order to allow insertion of two heavy nonabsorbable sutures in each tuberosity (Ethibond No. 5). A second pair of sutures is passed 1 cm proximal to the fracture line on the articular surface, and then two pairs of sutures are inserted laterally and medially through the diaphysis. The fractures are then "fixed" by tying the sutures in a tension band manner (Fig. 2).

A closely monitored 3-phase rehabilitation program was used and consisted of pendulum exercises initiated from the second postoperative day until the second to third postoperative week followed by passive assisted exercises (forward elevation, external and internal rotation) until the sixth to seventh postoperative week, and finally, active dynamic shoulder motion and strengthening exercises until the tenth to 12th postoperative week.

Digital angiographic assessment

Initial digital angiography of the proximal humerus was performed 6–12 h after admission and a second examination 8–10 weeks postoperatively. All patients had been fully informed about the investigation protocol and had agreed to undergo this invasive procedure for research purposes. The technique of angiography comprised selective catheterization of the axillary artery and a 10 ml bolus infusion of contrast medium (Iomeron 400 Bracco, Italy). The imaging recorded three views (face view, +45°, −45° tube angulation) in the shoulder region using 100 cm tube-amplifier distance and 50 cm tube-object distance with a Philips DVIS angiographic suite at 40 KVp, automatic exposure control and 1 image/s frame rate. Thirty views were taken so as to show the humeral head vascularization during the arterial and venous phase. Selected views (one image at every tube angulation) of the late arterial phase were digitized through a video grabber and sent to the Department of Medical Physics for further processing.

Angiographic imaging procession

The procedure of counting the area and length of the vessels includes a number of imaging processing steps. An irregular area of interest (AOI) is delineated in order to include the part of the image where the filtering operations take place (Fig. 3A). The image containing only the vessels of AOI is produced by a successive application of logical operations between the original image and appropriate masks created on the processed image above. Discrimination between large and small vessels is

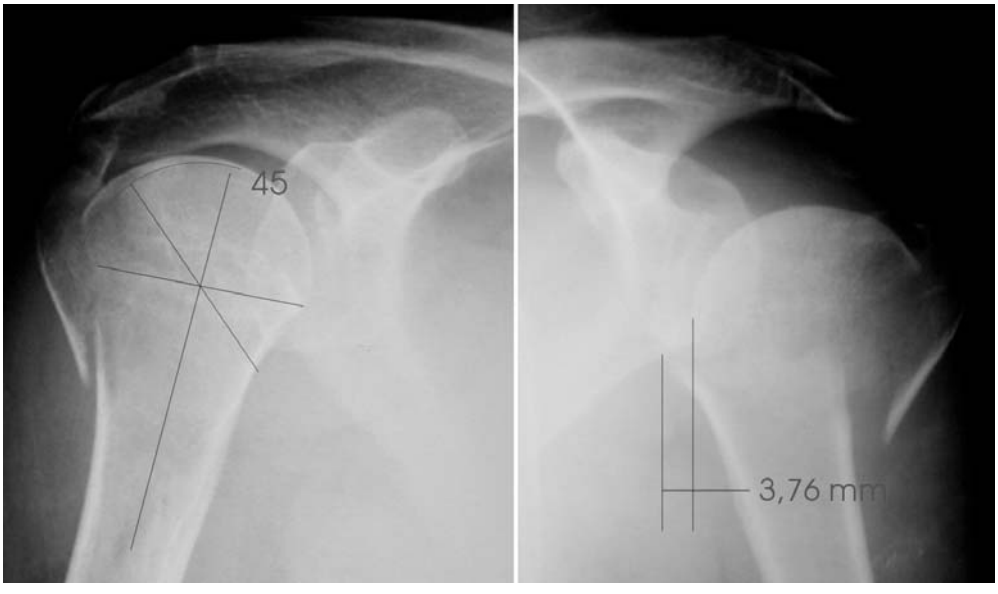

Fig. 1 Estimation of valgus impaction angle and lateral displacement of the humeral head using the metric parameters of the CorelDRAW 9 program

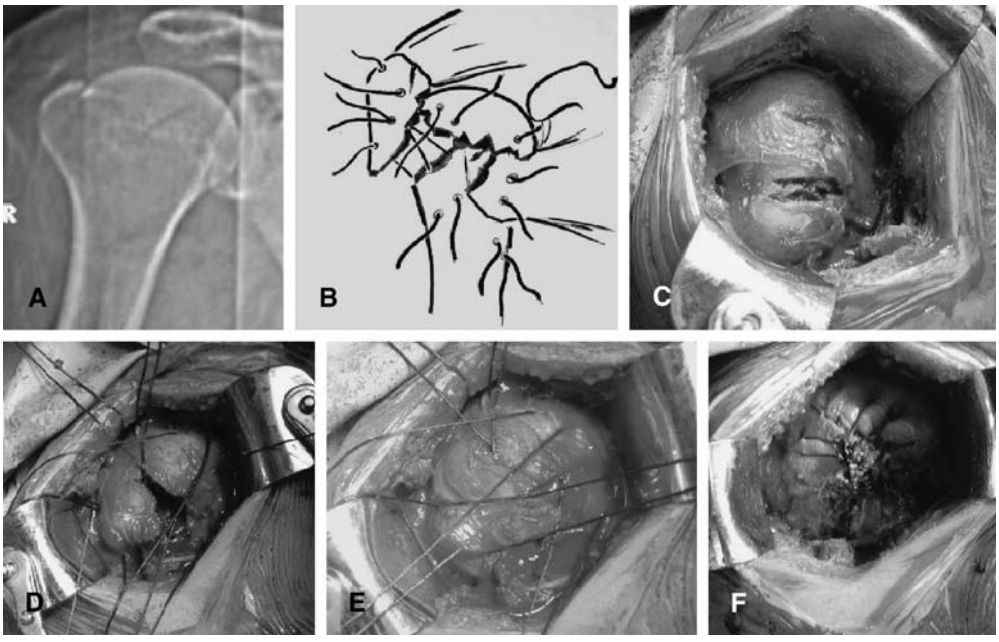

Fig. 2A–F Surgical technique of transosseous suturing. **A** CT-scan image of a true valgus impacted fracture with 45° of valgus impaction. **B** Schematic representation of the proposed technique. **C** Intraoperative images showing the fracture pattern, **D** the application of transosseous sutures both to the tuberosities, to the articular part and to the diaphysis, **E** the cruciate manner of fixation aiming to pull down the tuberosities below the level of the head, and **F** the final knotting resulting in stable fixation allowing for early joint motion

achieved based on the gray level value as the amount of radiopaque material is distributed proportionally to vessel size. Larger-diameter vessels are expected to absorb more radiation than smaller vessels, giving rise to darker gray level values on the original angiographic images. By applying suitable intensity filters, vessels exceeding a predefined value in diameter are isolated. "Large vessels" are considered to be those exceeding 0.5 mm in diameter. The total area of the vessels is counted separately on the images containing small and large vessels. The area is initially measured in pixels, but a normalization procedure follows, translating pixels into millimeters^2. The total length of the vessels is counted after the application of a binary "skeletonizing" operation that reduces vessel width to 1 pixel. The number of pixels is thus equal to the vascular total length. Normalization is achieved by measuring the width (in pixels) of a vessel of known size. We thus estimate a per-patient mean normalization factor, and this is used for transforming vessel length from pixels to millimeters. Areas are accordingly transformed into millimeters^2, taking into account error propagation. Length and area are thus measured independently of the image's specific magnification and permit their comparison among different patients (Fig. 3). Statistical analysis

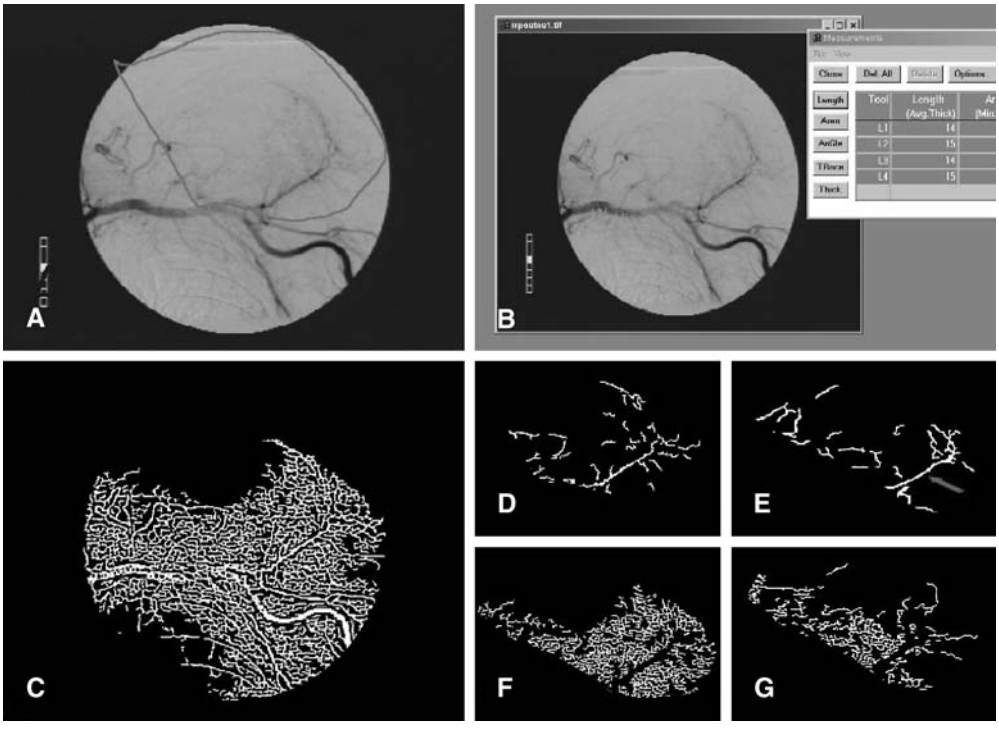

Fig. 3A–G Digital angiographic imaging process. **A** Area of interest. **C** Total length and area of both small and big vessels after the imaging procession. **D** Preoperative length, **E** postoperative length, **F** preoperative area **G** postoperative area of small vessels in the area of interest. Note that the arcuate artery (*red arrow*) is preserved postoperatively, and that there is a reduction of both the length and total area of small vessels indicating union at the time of investigation (6–8 weeks postoperatively)

is done according to the parameters of paired *t* test and its nonparametric form (Wilcoxon test). Overall statistical significance was set at $p<0.05$.

Results

All patients except one were available for final assessment. There were no wound complications, infections, or radiological evidence of loss of reduction. In the final radiographs, there were no signs of posttraumatic arthritis, nonunion, or severe collapse of the head. There was only one patient with partial AVN of the head. All patients were satisfied with their result, with no pain during vigorous activities and being able to resume their previous levels of daily and recreational activities. The average Constant–Murley score was 87 (67–100) points, and the functional score in comparison with the unaffected shoulder was 94% (89–100%).

Digital angiographic imaging showed neither statistical difference in the average length of large vessels nor in the mode of blood supply in the particular AOI before surgery and after the healing period ($p>0.05$). Only the small vessels were significantly affected; both their length and their AOI were significantly ($p<0.05$) smaller 6–8 weeks postoperatively (Table 1). This reduction could be explained by the stage of union at the time of investigation. A larger number of small vessels would only be expected in the presence of either nonunion or delayed union, as the progress of healing implies an inhibition of revascularization and angiogenesis.

Discussion

Displaced fractures of the proximal humerus carry a significant risk of aseptic AVN of the humeral head, and knowledge of the vascularization of the humeral epiphysis allows understanding of this problem. Studies on this subject, particularly those of Gerber [5], have emphasized the role of the intraosseous anastomoses arising from the anterior circumflex humeral artery and especially from the branches of the lateral ascending artery. This vessel runs along the lateral edge of the bicipital groove and continues as an arcuate artery after its penetration into the bone. Brooks et al. [1] found a significant arterial anastomoses between the arcuate artery and the posterior circumflex humeral artery arising from vessels entering the posteromedial aspect of the proximal humerus. The arcuate artery also anastomoses with metaphyseal vessels and vessels of the greater and lesser tuberosities. In contrast, Duparc et al. [3] stressed the important contribution of the arterial blood supply from the posterior circumflex artery, especially to the subchondral bone of the humeral head. Our angiographic imaging procession showed that the arterial supply of the humeral head arises mainly from the arcuate artery and from several anastomoses arising from the posteromedial capsule and the tendons of the rotator cuff.

The four-part valgus impacted fracture according to Neer [15] is expected to have a lower incidence of AVN because some of the posteromedial neck vessels may be preserved if the periosteum remains intact in that region and the lateral displacement of the head is either nil or minimal.

Many operative techniques and fixation methods have been used to treat displaced proximal humeral fractures [2, 4, 6, 8, 9, 11, 13, 14, 16, 19, 20, 21]. Current trends in surgical technique for four-part "valgus impacted" fractures include limiting soft tissue dissection around the fracture fragments, reduction of the head to its anatomical position, and minimally invasive osteosynthesis [10, 12, 17–19, 22]. Apart from the risks of AVN, loss of reduction, and failure of osteosynthesis, implant complications such as breakage or migration, joint or neurovascular damage, and infection can occur [2, 6–8, 11].

Jacob et al. [12] reported nine patients of whom five were treated with closed reduction and percutaneous K-wire (KW) fixation and 14 with an open procedure with minimal internal fixation using KW, screws, or KW and cerclage wiring. Twenty-six percent developed AVN while 74% were satisfactory or excellent. Resch et al. [17] reported 22 patients who had a deltopectoral approach for internal fixation with KW from the shaft into the head combined with osteosutures to fix the tuberosities. Autogenous cancellous bone grafting was used in all cases, and the AVN rate was 9%. In 1997, the same author reported on 13 patients after a closed technique of percutaneous reduction, KW, and screw fixation. One patient developed AVN, a rate of 7.6% [18]. Yu et al. [22] reported eight patients with nine four-part valgus impacted fractures without any lateral displacement of the head treated with the screw-wiring technique and autogenous bone grafting. He had excellent results without any AVN. Recently, Hockings and Haines [10] followed 11 patients treated with a minimally invasive technique of transosseous suturing without the use of bone grafting or implants. The results were quite good with a 9% rate of AVN. Finally, Robinson et al. [19] reported 25 patients with four-part valgus fractures treated with open reduction of the head, filling of the metaphyseal cavity with Norian Skeletal Repair System (SRS) bone substitute, and internal fixation using isolated screws or buttress plates. No patient

Table 1 Statistical analysis of the length and area of larger and smaller vessels (total results)

	Preoperative	Postoperative	Paired *t* test/Wilcoxon test
Area of bigger vessels	1,254±524 mm^2	304±60 mm^2	$p>0.05$
Length of bigger vessels	1,255±418 mm	362±68 mm	$p>0.05$
Area of smaller vessels	1,007±164 mm^2	499±96 mm^2	$p<0.05$
Length of smaller vessels	1,444±217 mm	761±111 mm	$p<0.05$

had signs of osteonecrosis at their latest follow-up, and the mean Constant score was 80 at 1 year.

The use of heavy nonabsorbable transosseous sutures is our choice for the fixation of four-part valgus impacted fractures. This technique has two critical and important points. Firstly, we do not elevate the impacted articular fragment from the diaphysis thus minimizing the potential risk of further disruption of the posteromedial hinge. Secondly, the tuberosities are pulled down below the level of the head and sutured in a tension-band manner not only to each other but also both to the articular fragment and to the diaphysis. This provides stable fixation with adequate rotator cuff repair and normal functional balance of the involved muscles and tendons that allows early shoulder joint motion.

After a minimum follow-up of 36 months we had only one case of partial AVN in a fracture with a 7 mm lateral displacement of the head. There were no instances of nonunion or loss of reduction. The functional Constant score was 94%, and all our patients were satisfied with the result.

The present study has several limitations. Firstly, the number of examples is small because many patients refused to undergo angiography. Secondly, we attribute our good results to careful surgical technique, especially the sole use of osteosutures and careful minimal dissection. However, precise assessment of these surgical details is difficult. Finally, there is no standard method of measuring head-shaft angles on AP radiographs. The humeral head is often either internally or externally rotated, and this alters the head-shaft angle. An effort was made in all these patients to obtain AP views in zero rotation and to estimate the head-shaft angle using scanned images imported to the CorelDRAW 9 program. Additional CT-scan images can help to demonstrate true four-part valgus impaction of the proximal humerus (Fig. 2a).

Despite these limitations, we recommend the use of open reduction and minimal internal fixation. Postoperative dynamic digital angiography showed that the endosteal supply of the humeral head was preserved in most of our patients.

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