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ORIGINAL PAPER

Hemiarthroplasty for proximal humerus fractures with conservation of the whole humeral head as autograft: does it improve greater tuberosity healing?

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Abstract

Purpose Hemiarthroplasty (HA) for proximal humerus fracture (PHF) is associated with tuberosity complications like migration, non-union, and resorption. In order to improve the rate of consolidation of the greater tuberosity (GT), we have developed a hollow humeral head prosthesis in which the whole humeral head is inserted and used as autograft. This study is designed to evaluate the consolidation rate of the GT with this device.

Method Twenty-two patients at mean age of 68 were treated between 2015 and 2017 for four-part fractures, fracture-dislocations, and head-split fractures with HA including the bony humeral head. The humeral prosthesis device comprises a prosthetic cephalic cup in which the detached humeral head is inserted and a cementless adjustable humeral stem which works like a jack. Mean follow-up was 14 months. The consolidation of GT was followed on X-rays. As comparison, 15 published series were selected and analyzed.

Results There were two mechanical complications related to GT consolidation (9.1%). In the 20 other cases, the GT was radiologically consolidated without displacement. While the raw proportion of complications observed in the present series was lower than that reported in each of the 15 comparative series, the proportion of complications observed in the present series was significantly different from that observed only in seven out of the 15 previous series.

Conclusion Whole conservation of the humeral head as an autograft along with proper surgical technique yielded in 20 consolidations of GT without displacement in 22 cases of PHF treated with hemiarthroplasty.

Keywords Humeral autograft · Proximal humerus fracture · Shoulder hemiarthroplasty · Tuberosity

Introduction

Primary hemiarthroplasty (HA) is an established surgical method for complex fractures of proximal humerus like four-part fractures, fracture-dislocations, and fracture with humeral head-split [1–6]. However, significant post-operative complications related to the tuberosities have been reported with this procedure [1–5, 7–13]. These complications include secondary migration, tuberosity resorption, non-union, and lead to poor functional outcome. To avoid these complications, many authors have emphasized the importance of a strong and anatomical fixation of the tuberosities [1, 6, 14]. Some have questioned the role of the design of the humeral prosthesis [13–15] and a growing number gives up HA and advocates the use reverse shoulder arthroplasty (RSA) [16–18].

Our experience with an intrafocal device for open reduction and internal fixation (ORIF) enabled us to obtain healing of tuberosities quasi-systematically [19, 20] and drove us to explore an original solution to improve tuberosities consolidation in humerus arthroplasty for trauma. Instead of discard the humeral head or to fragment it as chips of bone graft, we insert it in a hollow prosthetic humeral head. Thus, fixation of the tuberosities places them in close contact with the original

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humeral head. In order to evaluate the benefit of the conservation of the humeral head as autograft on the rate of consolidation of the greater tuberosity (GT) in HA, we studied our first cases with this procedure and compared our results with those of the surgical literature.

Materials and methods

Patients

Between mid-2015 and 2017, 24 patients were treated in our institution for proximal humerus fracture by hemiarthroplasty with conservation of the whole humeral head as autograft included in the cephalic prosthetic cup. Two patients were lost to follow-up. This study includes 22 fractures in 22 patients. According to the Neer classification [6], there were seven four-part fractures, ten anterior fracture-dislocations, three posterior fracture-dislocations, and two head-split fractures. There were 17 woman and five men. The mean age was 68 years (33–86).

All patients had standard AP and lateral X-rays and in 17 cases a preoperative CT-scan was performed.

Surgical technique and follow-up

Three different surgeons performed all surgery. The prosthesis used for this operation is made of two parts. The first part is a hollow chrome-cobalt cephalic cup with a female Morse taper cone and the second part a cementless adjustable stem made of titanium with a male Morse taper cone (Just Unic, Evolutis, Briennon, France). The cephalic cup has a 2.5-mm thickness. It comes in four sizes and for each size there is a centered or an offset female Morse taper cone. The cementless stem is the same one used for ORIF by intrafocal distraction [19]. It comes in three sizes and is made of three components: a sort of trapezoid section (wedge), a sliding stem, and a locking screw. The trapezoid section is designed to be settled into the diaphysis. This section is crossed by a sliding stem fitted with a Morse taper tilted at 130° on the vertical axis. The stem and the trapezoid section are locked together by a locking screw. When the locking screw is removed, the stem slides into the section. Once the wedge is press fitted into the diaphysis, the sliding stem can be distracted by levels of 6 mm. The maximal possible distraction is 18 mm (three notches).

The patients are operated in beach-chair position under fluoroscopic control through a lateral deltoid split approach in 16 cases and deltopectoral approach in six cases. Removal of the humeral head is the first part of the procedure and the whole head is kept aside to be included in anatomical position in the hollow cephalic prosthetic cup. The next step of the operation is to prepare the diaphysis. This part of the procedure is the same that the one described for ORIF by intrafocal distraction [19]. Two holes are drilled in the external cortical bone of the diaphysis to pass two strong sutures (Ethibond Excel6™) ready for final suture of the GT. A trial stem is placed in the diaphysis under fluoroscopic control in order to choose the proper size of the final cementless stem. The axial position of the stem is determined according to the metaphyseal anatomy: the metaversion is highly predictive of humeral head version [21]. Then, the final cementless adjustable stem is press fitted into the diaphysis. Trial cephalic cups are used under fluoroscopic control to determine the proper level of ascension of the sliding stem and to choose between the centered cup and the offset cup. The proper level and the proper offset are the one who restore the anatomical metaphyseal curve. Once the type of cup is determined, the humeral head is perforated centrally or eccentrically and the final cephalic cup is pushed over the perforated humeral head (Fig. 1a–c). The prosthetic cup including the humeral head as autograft is replaced in the joint and with movements of the

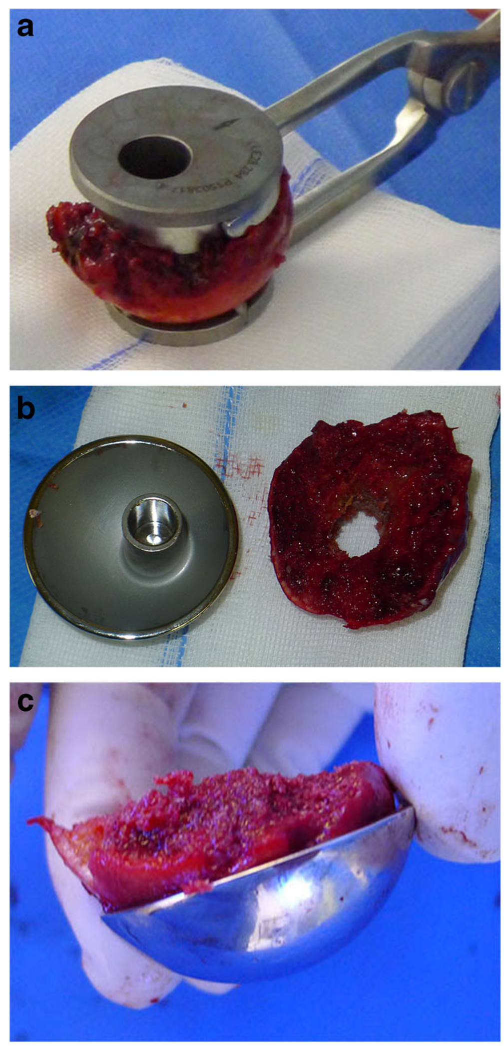


Fig. 1 **a** Special clamp to perforate the humeral head. **b** Eccentrically perforated humeral head and offset cephalic cup. **c** The humeral head is inserted in the cephalic cup

arm, the male Morse taper cone of the cementless stem is introduced in the female Morse taper cone of the cephalic cup (Fig. 2a, b). Once the cup and the stem are united, the stem is distracted with a distractor under fluoroscopic control until the anatomical curve of the medial humerus metaphysis is restored Fig. 3a, b). A locking screw locks the sliding stem to the trapezoid section at the chosen level.

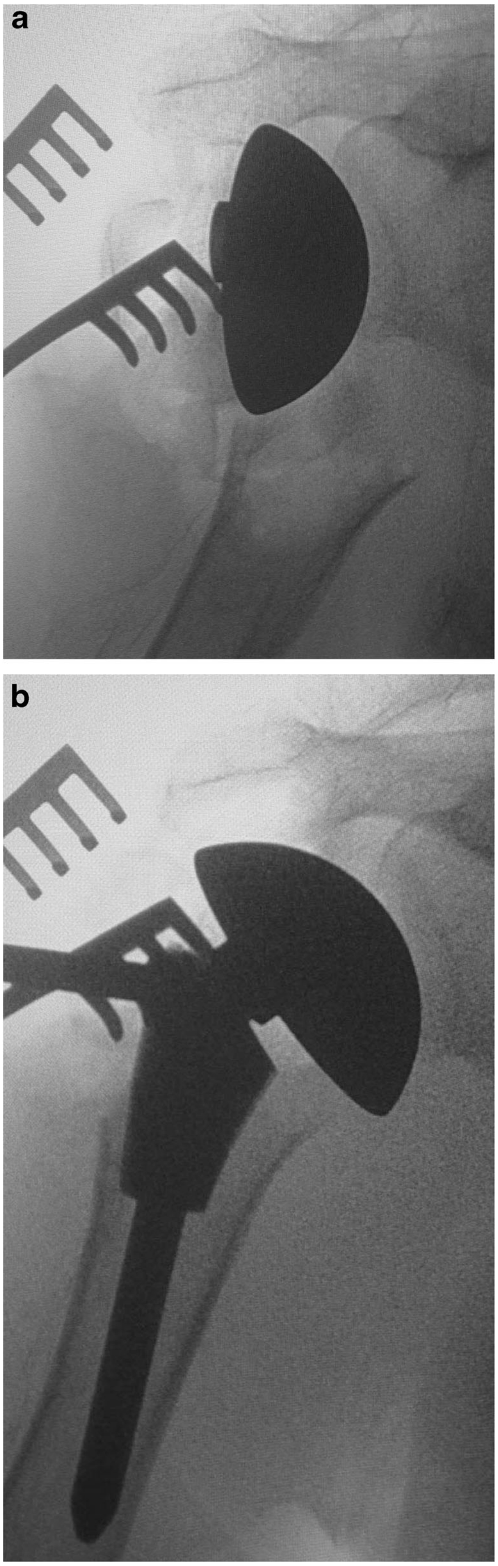


Fig. 2 **a** The prosthetic cup including the humeral head is placed in the joint. **b** Union of the stem and the cephalic cup

The rest of the operation consists of suturing the tuberosities. Heavy sutures are passed one in the subscapularis tendon at it insertion on the lesser tuberosity and the other in the tendon infrasupinatus at its insertion on the GT. Tightly knotting these two sutures achieves horizontal fixing of the tuberosities.

Finally, the two sutures passed through the diaphysis are passed through the supraspinatus tendon achieving a double tension band vertical fixation in figure of 8, between the shaft and the cuff. Post-operatively, the arm is immobilized in a sling and physiotherapy starts between the fourth and the seventh day by passive mobilization. Active motion starts after one month.

The patients were seen regularly for clinical and radiological follow-up. The mean follow-up was 14 months (6–40).

The clinical parameters evaluated at final follow-up were raw and weighted constant score (CS) [22].

Radiological assessment was based on the AP and lateral X-rays. We searched by comparison between post-operative and last follow-up X-rays, resorption, non-union or displacement of the GT, and proximal migration of the humeral head. Measurements were made on post-operative and last follow-up AP X-rays with the prosthesis on its coronal plane aspect (Fig. 4). The known diameter of the prosthetic cup gives the scale for bony measures. Axis of the proximal humerus (X_1X_2) was obtained through three midpoint determinations of the proximal humerus shaft.

The vertical position of the GT was assessed by the distance between two horizontal lines: line A is tangent to the top of the prosthetic head and perpendicular to the axis X_1X_2 of the proximal shaft; line B is tangent to the summit of the GT and perpendicular to the axis X_1X_2.

The horizontal position of the GT was also evaluated. The offset of the GT is the distance between the axis X_1X_2 and a line C tangent to the most lateral aspect of the GT and parallel to the axis X_1X_2. A difference of more than 2 mm of the GT position between the post-operative and last follow-up x-ray was considered as displacement.

Acromiohumeral space was evaluated by measurement of the distance between the summit of the prosthetic head and the line of sclerosis of the acromion, on initial and final AP radiographs.

Statistical analyses

As for comparison, we carried out a bibliographic research on hemiarthroplasty for proximal humeral fractures and selected 15 articles [2, 3, 8–13, 15, 23–28] (Table 1) with the following criteria:

Fig. 3 **a** Distraction of the stem until restoration of the curve of the medial humeral metaphysis. **b** Restoration of metaphyseal anatomy is facilitated by conservation of the humeral head

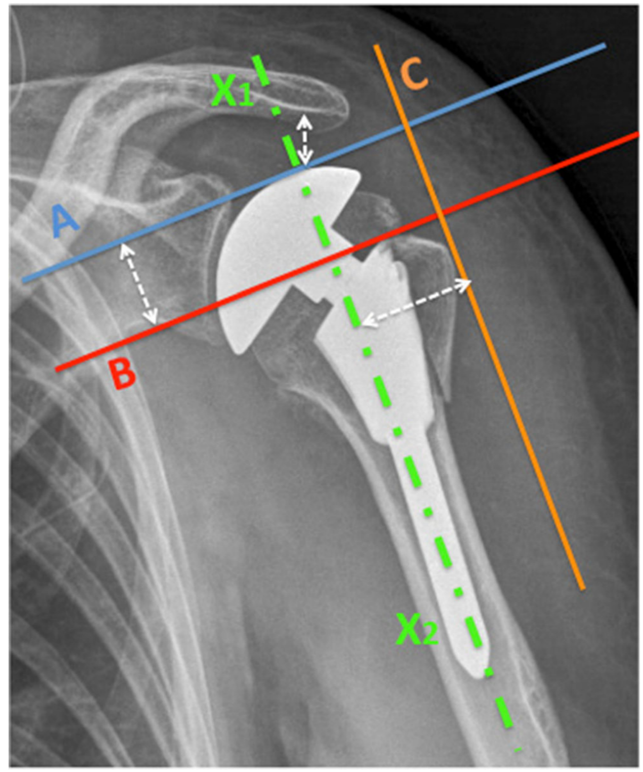


Fig. 4 Radiological measures. X_1X_2: axis of the proximal humerus. Line A: tangent to the humeral cup and perpendicular X_1X_2. Line B: tangent to the most superior aspect of GT and perpendicular to X_1X_2. Line C: tangent to the most lateral aspect of GT and parallel to X_1X_2. The distance between A and B gives the vertical position of the GT. The distance between X_1X_2 and C gives the horizontal position of the GT. Acromiohumeral space: distance between the summit of the prosthetic head and the line of sclerosis of the acromion

- Published in English in the past 20 years
- Proximal non-pathological humeral fractures treated by hemiarthroplasty in skeletally mature patients
- Radiological evaluation of the tuberosities at the last follow-up
- Not less than 20 patients evaluated radiologically

In case of multiples studies concerning the same humeral prosthesis, we choose the papers from authors not involved in the development of the implant. The selected complications related to GT at last follow-up were displacement of 1 cm or more, non-unions, frank resorption, and proximal migration of the humeral head. We did not include initial misplacement, malunion, or partial resorption.

The 95% confidence interval (95% CI) of the proportion of complications observed in the present surgical series was calculated according to the method of Agresti and Coull [29]. The criterion retained for comparing the present series to the series previously reported was the proportion of complications. Since the sample sizes of surgical series are likely modest (including that of the present study), in a first step, we examined whether

Table 1 Comparison of the proportion of complications reported in 15 selected published series with that observed in the present series*

Published series (first author, year)	Complications/sample size (*n*/*N* and corresponding proportion)	Difference between the proportion of complications reported in the publication and the proportion of complications observed in present series (mean estimate of the difference [95% CI])
White (2017)	12/026 and 0.4615	0.3706 [0.0101; 0.6685]**
Hashiguchi (2015)	07/035 and 0.2000	0.1091 [− 0.1802; 0.3627]
Andres-Cano (2015)	06/021 and 0.2857	0.1948 [− 0.1538; 0.5125]
Boons (2012)	05/025 and 0.2000	0.1091 [− 0.2001; 0.3945]
Liu (2011)	16/033 and 0.4848	0.3939 [0.0536; 0.6678]**
Reuther (2010)	66/102 and 0.6471	0.5561 [0.2857; 0.7527]**
Amirfeyz (2008)	05/039 and 0.1282;	0.0373 [− 0.2263; 0.269]
Antuna (2008)	10/035 and 0.2857	0.1948 [− 0.1146; 0.4592]
Grönhagen (2007)	24/046 and 0.5217	0.4308 [0.1153; 0.6763]**
Loew (2007)	17/039 and 0.4359	0.3450 [0.0221; 0.6059]**
Kralinger (2004)	77/167 and 0.4611	0.3702 [0.1161; 0.557]**
Mighell (2003)	16/072 and 0.1806	0.0896 [− 0.1671; 0.2954]
Robinson (2003)	53/138 and 0.3841	0.2931 [0.0362; 0.4852]**
Demirhan (2003)	05/032 and 0.2188	0.1278 [− 0.1715; 0.3921]
Boileau (2002)	15/066 and 0.2273	0.1364 [− 0.1307; 0.3513]

In the present series, there were two patients with complications among the 22 treated patients, and the corresponding proportion of complications [95% CI] is 0.0909 [0.0134; 0.2900]

CI confidence interval

[a] The difference between the two proportions is statistically significant (n.b., in order to take into account the non-independent multiple ($n = 15$) comparisons made, a Dunnett-like correction was applied, see "Material and methods")

previous studies could be pooled or not: comparing our series to a unique pool would have a much greater statistical power than that associated with multiple individual comparisons of our series with each of the individual series previously reported. Therefore, based on a meta-analysis of the studies previously reported, examining the heterogeneity between studies using the I^2 criterion [30] was the first analysis planned. It was a priori decided that if this examination resulted in a substantial heterogeneity preventing pooling, multiple comparisons should be performed, and in order to take into account the non-independence of such multiple tests, a Dunnett-like method advised for comparing a single study to several others would be applied [31]. All analyses were performed using R statistical freeware version 3.5.0, and package «meta» [32] and package « BinMto » [31] were used for meta-analysis and Dunnett-like multiple comparisons, respectively.

Results

Clinical assessment

The mean raw CS was 52 points (range 40–74) and the mean weighted CS 73% (46–100). Two patients have neuropsychological problem that impaired physiotherapy (cases 12 and 16). One patient died at 1 year from diseases unrelated to the humerus fracture (case 11). One patient had complex regional pain syndrome (case 19) (Table 2).

Radiological assessment

There were two cases of displacement of the GT. In case 5, the patient felt at home and early follow-up showed fracture of the lateral cortical metaphyseal bone and valgus of the prosthesis. In case 13 at three month follow-up, the GT was completely detached and the proximal humerus ascensioned.

In all other cases, there were no displacements of the GT, neither non-union nor resorption (Fig. 5). Except for case 13, there was no upper migration of the humeral prosthesis.

There were three cases of heterotopic ossifications (HO) (cases 9, 17, 18).

In the present series of 22 treated patients, complications were observed in 2 patients, and the corresponding proportion estimate (95% CI) was therefore 0.0909 (0.0134; 0.2900). Considering the 15 series previously reported, the proportions of complications reported ranged from 0.13 to 0.65. As shown in the forest plot issued from the meta-analysis, the I^2 value of 87% indicated a considerable heterogeneity of the 15 series previously published, preventing pooling these studies in order to make a single comparison of our series with such a

Table 2 Individual characteristics and results

Case No.	Age	Sex	Pre-operative X-rays	Postop X-rays Heah-GT height	FU month	GT on X-rays at last FU: Shifting	Non-union	Resorption	Constant score: Raw	Weighted
1	69	F	Anterior fracture-luxation	12 mm	27	0	0	0	67	96%
2	86	F	Anterior fracture-luxation	10 mm	13	0	0	0	51	80%
3	79	F	Anterior fracture-luxation	6 mm	40	0	0	0	59	86%
4	75	F	Head-split fracture	12 mm	20	0	0	0	54	78%
5	84	F	Anterior fracture-luxation	25 mm	24	Lateral shifting after metaphyseal fracture			38	59%
6	60	F	Anterior fracture-luxation	8 mm	27	0	0	0	64	88%
7	81	F	4-part fracture	11 mm	32	0	0	0	59	92%
8	81	F	4-part fracture	10 mm	14	0	0	0	74	100%
9	58	F	4-part fracture	1 mm	8	0	0	0	63	88%
10	87	F	Anterior fracture-luxation	14 mm	11	0	0	0	48	75%
11	70	F	Anterior fracture-luxation	16 mm	7	0	0	0	29	41%
12	33	M	Posterior fracture-luxation	12 mm	18	0	0	0	57	61%
13	81	F	Anterior fracture-luxation	9 mm	5	Complete displacement			34	53%
14	66	F	4-part fracture	6 mm	8	0	0	0	51	73%
15	50	F	Anterior fracture-luxation	11 mm	8	0	0	0	61	76%
16	54	M	Posterior fracture-luxation	12 mm	8	0	0	0	53	59%
17	65	M	Head-split fracture	16 mm	6	0	0	0	59	71%
18	59	M	4-part fracture	10 mm	8	0	0	0	40	46%
19	83	F	4-part fracture	13 mm	6	0	0	0	42	66%
20	56	F	4-part fracture	15 mm	7	0	0	0	47	64%
21	51	M	Posterior fracture-luxation	12 mm	6	0	0	0	53	56%
22	71	F	Anterior fracture-luxation	12 mm	6	0	0	0	60	87%

study pool (Table 3). Therefore, individual comparisons with each of the studies previously published were performed (Table 1): while the raw proportion of complications observed in the present series was lower than that reported in each of the 15 previous series, the proportion of complications observed in the present series was significantly different from that observed in 7 [3, 8–10, 15, 26, 27] out of the 15 previous series.

Discussion

Our study oriented toward consolidation of GT shows a 9.1% complication rate, which compares favorably with the 15 studies selected though the difference was statistically significant in only seven series. It must be emphasized that we could not assess always properly the consolidation of the lesser tuberosity and thus our discussion concerns only the GT. Tuberosity healing is not renowned as an issue in ORIF for proximal humerus fractures [33, 34] and that is also our experience with ORIF by an intrafocal distraction device [19, 20]. After ORIF by such an intrafocal device, the GT regularly healed even in cases of subsequent avascular necrosis. With hemiarthroplasty, the concern of GT consolidation was raised by the first users and confirmed since by many authors [1–5, 7–14]. The proper positioning of the implant is surely important to minimize this complication but removal of the humeral head and fixation of tuberosities against a metallic prosthesis is part of the problem. To address this issue, proper fixation techniques of tuberosities have been highlighted. The use of an implant designed specifically for fractures, with low metaphyseal component that allows bone grafting has been advocated by Boileau [13, 14]. However, Loew [9] concluded in a comparative study of this implant that: "The prosthesis which was specially designed for fractures does not lead to improved osseous integration of the tuberosities. The overall results obtained by the standard and trauma prostheses were very similar." Besides Boileau himself concluded his article of 2013 [14] about his specific fracture prosthesis by this sentence: "On the basis of the results of this study, in case of displaced 3- or 4-part fractures, we now perform an RSA instead of an HA in patients aged 75 years or older, who have poor bone quality." Conversely, instead of using a low profile fracture stem, other authors advocated a large metaphyseal volume stem with the hypothesis that healing of GT could be achieved with a metallic scaffold [35]. But in their analysis of 26 patient with a large metaphyseal volume shoulder hemiarthroplasty, White et al. [15] stated "Our impression

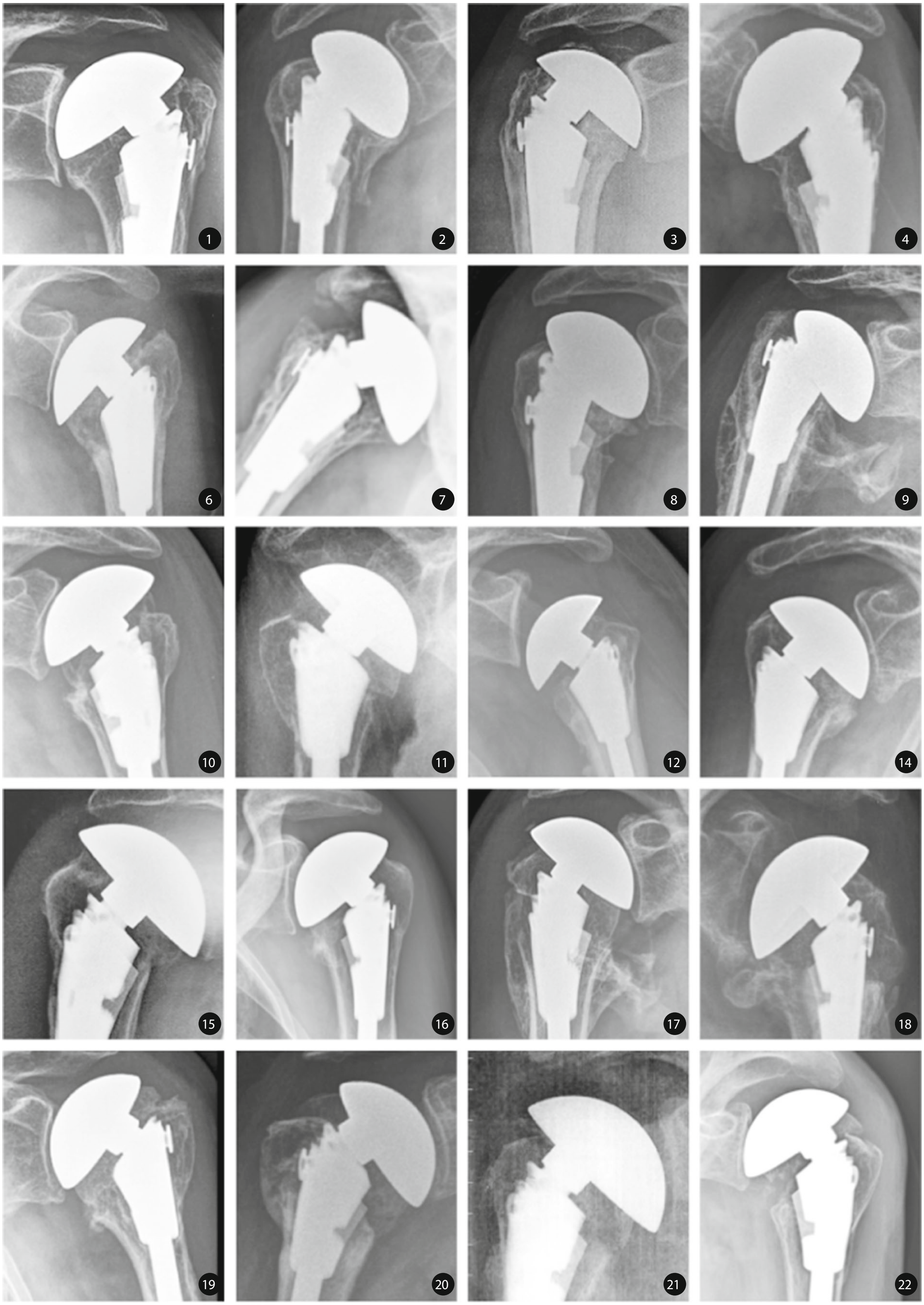
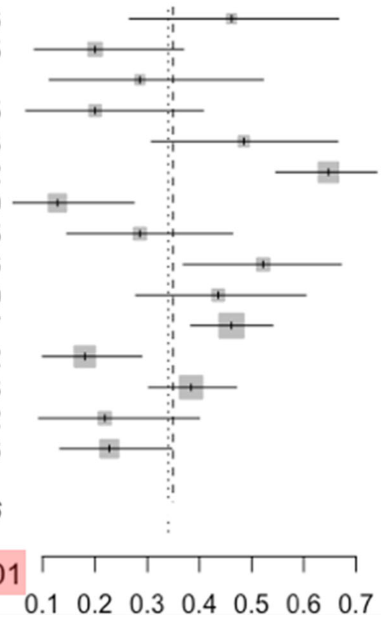


Fig. 5 AP views at last follow-up of the 20 cases of consolidation of GT without displacement. Cases 5 and 13 are excluded

Table 3 The forest plot

Study	Events	Total	Proportion	95%-CI	Weight (fixed)	Weight (random)
White, 2017	12	26	0.46	[0.27; 0.67]	2.4%	5.7%
Hashiguchi, 2015	7	35	0.20	[0.08; 0.37]	5.1%	6.7%
AndresCano, 2015	6	21	0.29	[0.11; 0.52]	2.4%	5.7%
Boons, 2012	5	25	0.20	[0.07; 0.41]	3.6%	6.3%
Liu, 2011	16	33	0.48	[0.31; 0.66]	3.1%	6.1%
Reuther, 2010	66	102	0.65	[0.55; 0.74]	10.3%	7.3%
Amirfeyz, 2008	5	39	0.13	[0.04; 0.27]	8.1%	7.1%
Antuna, 2007	10	35	0.29	[0.15; 0.46]	4.0%	6.4%
Gronhagen, 2007	24	46	0.52	[0.37; 0.67]	4.3%	6.5%
Loew, 2007	17	39	0.44	[0.28; 0.60]	3.7%	6.3%
Kralinger, 2004	77	167	0.46	[0.38; 0.54]	15.5%	7.5%
Mighell, 2003	13	72	0.18	[0.10; 0.29]	11.2%	7.3%
Robinson, 2003	53	138	0.38	[0.30; 0.47]	13.5%	7.4%
Demirhan, 2003	7	32	0.22	[0.09; 0.40]	4.3%	6.5%
Boileau, 2002	15	66	0.23	[0.13; 0.35]	8.7%	7.2%
Fixed effect model		*876*	*0.35*	*[0.32; 0.38]*	*100.0%*	*--*
Random effects model			*0.34*	*[0.26; 0.43]*	*--*	*100.0%*

Heterogeneity: $I^2 = 87\%$, $p < 0.01$



Estimates that would be issued from models based on fixed or random effects are shown in italics

of the large metaphyseal design is that the tuberosities require debulking to achieve adequate positioning and reconstruction around the prosthetic 'shoulder,' and we wonder whether this contributes to poor healing or tuberosity resorption, or both." They also conclude: "In selected patients, primary reverse total shoulder arthroplasty may provide a more suitable alternative to hemiarthroplasty."

These conclusions are in line with the growing tendency to implant of reverse arthroplasty in trauma [16–18]. Despite all the complications associated with reverse shoulder arthroplasty [36, 37], this trend may reflects the frustration of surgeons with the results of hemiarthroplasties.

Our study shows that healing of GT is not such a difficult goal to reach. The humeral head conservation as autograft allows the tuberosities to be fixed in the same bony environment than in ORIF. Next, the humeral bony head conservation makes it easier to assess the proper height of the prosthesis tanks to the restoration of the medial metaphyseal curve (Fig. 3). Last, the adjustable cementless stem contributes probably to the good results because it makes the proper positioning of the humeral prosthesis controlled and simple. In the nine patients older than 74 years (mean age 82), there was only one case of early pull off of tuberosities and the other eight consolidated their GT. As we note in trochanteric fractures, osteoporosis is not a risk factor for the development of non-union [38]; the problem is more about the quality of fixation. Thus, there is no reason why a strong suture of GT in a proper bony environment should not lead to consolidation. The suture technique that we use is not original [1, 5, 11] and the vertical fixation of GT to the shaft with one or two figures of 8 heavy sutures is of paramount importance. Anatomically, the summit of the humeral head is above the most superior aspect of GT. According to three anatomical studies, this distance ranges from 3 to 20 mm with averages between 6 and 8 mm [39–41]. In at least three of our cases (nos. 5, 11, 17), GT appears to be fixed a little too low but without repercussion on consolidation. One consequence of the humeral head inclusion in a prosthetic cup is that the prosthetic humeral head is 2.5 mm thicker than the original head because of the thickness of the metallic cup and this raise the question of an eventual effect on the glenoid in the long term. In our study, only five patients had a follow-up of 2 years and more. In these cases, there are no radiologic signs of glenoid wearing but more cases and longer follow-up are needed to verify this point. However, it is possible to remove the cartilage of the humeral head before inserting it in the cup the humeral head, which bring the size of the prosthetic cup closer to the original humeral head. Though our study is focused toward GT consolidation, the ultimate goal of healing of GT is to improve the functional results of hemiarthroplasty. Among the 15 articles chosen as comparison, seven indicated clearly that they used raw CS to evaluate their functional results. The average CS from these articles is 47 points. Though our 53 raw CS compares favorably, it is hazardous to draw any conclusion. There is a wide consensus about the regular association of a good functional result and healing of tuberosities but conversely the notion that healing of the tuberosities is constantly associated with good results is questionable. The anatomical repair of the proximal humerus is important and is somehow the responsibility of the surgeon but the functional results depend also greatly on the post-operative physiotherapy program and ultimately on the motivation of the patient. In our study, despite consolidation of GT, the functional result was poor at 7 months in a patient with failure to thrive who die at 1 year from complication not related to her fracture. Two patients with psychological problems had also a poor functional result (cases 12 and 16) and another had complex regional pain syndrome with 66% weighted CS at 13 months. Also, among the three cases of HO (cases 9, 17, and 18), one showed a poor functional result despite good consolidation of GT. However, our study shows that correct positioning of the humeral prosthesis and of the GT associated with conservation of the humeral head as autograft yield 90% healing of GT. This result is of importance in a time where many authors advise reverse shoulder arthroplasty rather than hemiarthroplasty for complex humeral fractures.

Conclusion

Whole conservation of the humeral head as an autograft along with proper surgical technique yielded 20 consolidations of GT without displacement in 22 cases. Our results suggest that the proposed technique deserves a great interest.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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