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Original Article

Tuberosity-overlapping Fixation of the Humeral Shaft in Humeral Head Replacement Surgery

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The fixation technique of bony fragments is crucial for the bone union of the tuberosities after humeral head replacement (HHR) for a comminuted fracture of the proximal humerus. To increase the bone union rate, we reduce tuberosities to overlap on the humeral shaft by approx. 1 cm and fix them with cable wire. Herein, we retrospectively investigated the clinical and radiographic outcomes of our procedure. Twenty-six patients who underwent cementless HHR for the treatment of comminuted fractures of the proximal humerus were investigated. The Constant-Murley score, active shoulder mobility, and bone union rate were evaluated. The mean duration of follow-up was 56.3 months (range 24-197). At the final follow-up, the average Constant-Murley score was 58 (range 40-76). Forward elevation was 126° on average (range 35°-180°). Twenty-three cases (88%) showed bone union between the tuberosities and the shaft at an average follow-up of 4.1 months (range 4-5 months) after surgery. Non-union was noted in 1 case, and bone resorption was noted in 2 cases. The bone union rate and the clinical outcome of our procedure were relatively favorable compared to the reported results of the conventional anatomical reduction technique for bone fragments.

Key words: humeral head replacement, tuberosity-overlapping technique, bone union of tuberosities, cable wire, cementless stem

Primary humeral head replacement (HHR) is a standard procedure for 4-part fractures, head-splitting fractures, or severe 3-part fracture dislocations of the proximal humerus [1,2]. The fixation technique for bony fragments is crucial for the bone union of the tuberosities, which represents one of the most influential factors in achieving a satisfactory clinical outcome [3-5].

In our procedure, the bony fragments of the greater and lesser tuberosities are overlapped by approx. 1 cm on the shaft and fixed with cable wire to improve the bone union rate. The use of a smaller size head and cementless stem are crucial for this procedure. We conducted the present study to retrospectively examine the clinical results of HHRs performed at our institute.

Patients and Methods

Between 2004 and 2016, 39 comminuted (4-part or 3-part) fractures of the proximal humerus were treated by an HHR at our institute. Four of these patients died for reasons not related to shoulder surgeries, and five patients were lost to follow-up. One patient declined participation in the follow-up study due to dementia. Three patients with severe osteoporosis who were

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treated with a cement stem were not included in this study. The complete clinical data of the remaining 26 patients with 26 HHRs were available for this retrospective analysis: 21 women and 5 men with an average age of 71.4 years (range 30-95 years). The average follow-up period after surgery was 56.3 months (range 24-197 months). This retrospective study was approved by the institutional review board (approval no. 49).

Of the 26 cases, 16 cases were 4-part and 10 cases were 3-part fractures of the proximal humerus. The period between the patient's accident and his or her surgery was within 1 week in 22 patients, within 2 weeks in 2 patients, and within 2 months in 2 patients.

All patients were treated with a cementless stem. A Bigliani Flatow® (Zimmer, Warsaw, IN, USA) was used for nine shoulders from 2004 to 2007. A Global Advantage® shoulder arthroplasty system (DePuySynthes, Warsaw, IN, USA) was used for 9 shoulders from 2008 to 2012, and a Global Unite system (DePuySynthes) was used for 8 shoulders from 2013 to 2016. All patients underwent clinical and radiologic examinations before surgery and at the final follow-up. The clinical results of each surgery were evaluated with the Constant-Murley score [6]. We divided the patients into the three-part group (n = 10) and the 4-part group (n = 16), and we compared the groups' clinical and radiographic results.

The bone union between the humeral shaft and tuberosities was assessed by 2 directions of radiographs using the antero-posterior view and true antero-posterior view with 30° of external rotation of the shoulder joint. Bone union was defined as the presence of dense bone structures between the tuberosities and the humeral shaft, assessed by 2 surgeons (T. H. and T. K.) who reached agreement.

Surgical technique. The delto-pectoral approach was used in all cases. The long head of the biceps tendon was separated from the fragment and preserved. The articular segment of the humeral head was then identified and removed. An artificial head was selected that was one size smaller than the resected humeral head, to allow the tuberosities to be easily pulled down around the shaft of the prosthesis. The humeral canal was then reamed manually. A cementless stem was press-fitted into the canal at 30° retroversion. The top of the prosthesis head was set approx. 40 mm above the proximal attachment of the pectoralis major tendon.

The fixation of tuberosity fragments was carried out with cable wires to fix them to each other and to the humeral shaft. We used TM cable wires (Zimmer) from 2004 to 2007 and TAN cable wires (DePuy Synthes) from 2008 for stronger fixation. One of 3 sutures was placed from the tuberosities to the humeral shaft, and the other 2 sutures were placed from the greater tuberosity through the holes in the fin of the prosthesis to the lesser tuberosity (Fig. 1). We reduced the tuberosities to create an overlap on the shaft of approx. 1 cm to facilitate bone union (Fig. 2).

Only when there is a space between the reduced tuberosities and the shaft, autogenous bone graft was taken from the extracted humeral head and applied there to enhance healing. After reduction, we con-

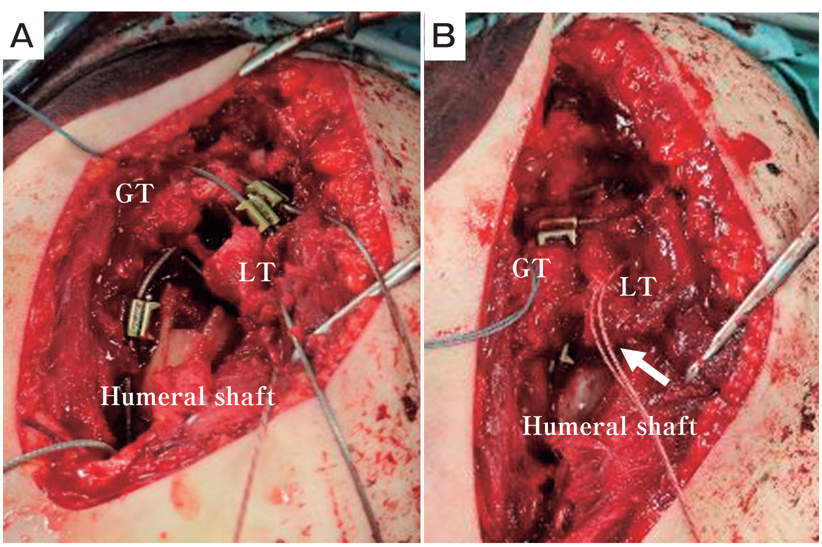

Fig. 1 Intra-operative findings showing the tuberosity-overlapping technique. A, Before reduction; B, After reduction. The arrow indicates tuberosities overlapped on the shaft.

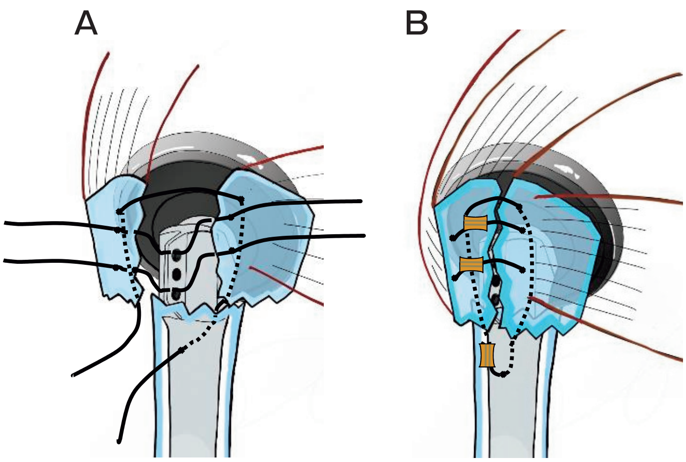

Fig. 2 Schematic representation of our tuberosity-overlapping technique with cable wires. A, Before the reduction of the tuberosities. Two of 3 sutures were placed from the greater tuberosity to the lesser tuberosity transversely. The third suture was placed from the tuberosities to the humeral shaft longitudinally; B, After tuberosity reduction.

firmed that the cable wire does not cause subacrominal impingement during shoulder flexion or abduction, and then the cable wire was fastened in front of the tuberosity fragment.

After surgery, the patient's operated arm was immobilized in a simple sling. All patients were encouraged to perform passive range-of-motion (ROM) exercises. The sling was removed at 3 weeks, and an active range of motion was started.

Results

At the final follow-up, the average Constant-Murley score was 58 (range 40-76). The average pain score was 13 points (range 5-15 points); the average activities of daily living (ADL) score was 14 points (range 6-20 points), the average ROM score was 28 points (range 16-38 points), and the average power score was 3 points (range 3-5 points) (Table 1). Nineteen patients (73%) reported no pain (Table 2). Forward elevation was 126° on average (range 35°-180°) (Table 3).

Twenty-three of the total of 26 cases (88%) showed bone union between the tuberosities and the shaft at an average of 4.1 months (range 4-5 months) after surgery (Fig. 3). Non-union was noted in 1 case. Resorption of bone fragments of the tuberosities was observed in 2 cases, one of which was a fracture caused by osteoporosis, and the other was a comminuted fracture of the tuberosities. Breakage of the cable wires occurred in 4 cases. In these cases, the cable wires were broken after bone unions. The patients did not complain of any pain due to impingement, and thus no additional surgery was required. There were no instances of glenohumeral dislocation, radiographic loosening, or infection.

The bone union rate was 90% in the 3-part group and 88% in the 4-part group. The mean Constant-Murley score was 58.2 points in the three-part group and 58.6 points in the 4-part group. There was no significant difference between the 3-part and 4-part groups in the bone union rate or the clinical outcomes. An autogenous bone graft was applied between tuberosities and the shaft in 2 patients. Bone union was

Table 1 Components of the Constant-Murley score

Components from Constant score		Mean	Median	Min	Max
Pain	(0–15)	13	15	5	15
ADL	(0–20)	14	14	6	20
ROM	(0–40)	28	28	16	38
Strength	(0–25)	3	3	3	5
Total	(0–100)	58	58	40	76

Table 2 Number of patients evaluated for pain

Severe pain	Moderate pain	Mild pain	No pain
0	1	6	19

Table 3 Number of patients in each range of forward elevation (degrees).

0–30	31–60	61–90	91–120	121–150	151–180
0	1	2	8	6	9

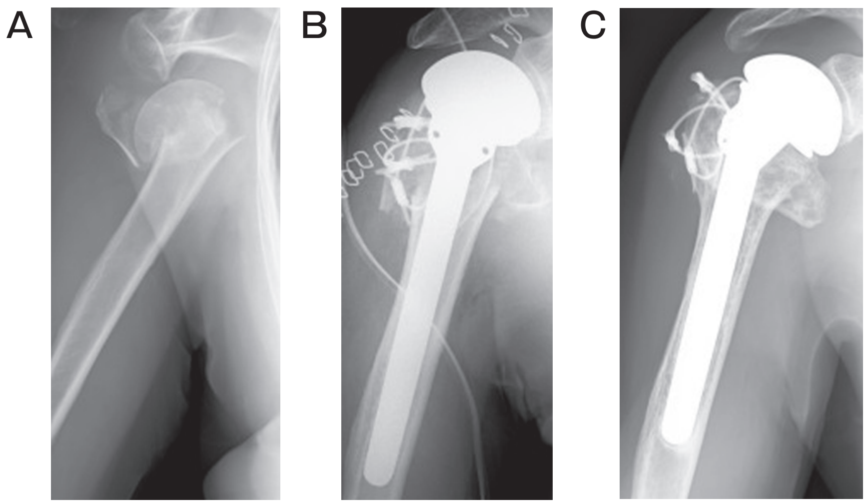

Fig. 3 A, Anterior-posterior radiographs taken preoperatively; B, Immediately postoperatively; C, At 4 months postoperatively, showing bone union.

obtained in both patients, and their Constant-Murley scores were 56 and 60 points respectively, which were comparable with the other cases.

Discussion

The results of open reduction and internal fixation are not always satisfactory in a displaced anatomical neck fracture or a fracture-dislocation of the humerus, Neer type III fractures, or fracture-dislocations in osteoporotic patients, or in head-split-type fractures [7]. Many authors have recommended the prosthetic replacement of the humeral head in these injuries [8-11]. Pain relief is usually achieved by an HHR; however, the functional result is less predictable [2, 12], partly due to non-union of the tuberosities. As displaced or resorbed tuberosities may lead to deleterious consequences, the bone union of the tuberosities appears to be a key factor in achieving good post-operative function [13].

The success of the surgery has been reported to depend on the ability of the tuberosities to heal themselves and on the reduction to the humeral shaft in anatomic positions surrounding the implant [14]. There are many reports of good bone union rates and functional outcomes [15-30] (Table 4). Most of these surgeries were conducted by reducing the tuberosities anatomically, using a cemented stem and nonabsorbable suture fixation. Boilieu *et al*. reported that 87% of tuberosities healed in the anatomical position when fractures were treated with a bone graft from the humeral head and nonabsorbable suture fixation [29]. Noyes *et al*. reported long-term outcomes of HHRs for 3- or 4-part proximal humeral fractures. In their report, the Constant-Murley score was 50 points on average, and 60% of the tuberosities were healed [30]. In the present study, the bone union rate and clinical results were comparable to or relatively better compared to those of the previous studies.

The main point of our technique described herein is the reduction of the tuberosities to overlap on the shaft by approx. 1 cm to improve bone healing between both tuberosities and the shaft. In an HHR with a press-fitted cementless humeral stem, the shaft is filled with the prosthetic stem. There is little contact surface between the tuberosities and the shaft. By reducing the tuberosities on the shaft to an approx. 1 cm overlap, we were able to secure a larger contact area between the tuberosities and shaft than can be obtained by anatomical reduction, which might be an advantage for fracture healing. For overlapped reduction, a head of one size smaller should be selected to enable the tuberosities to be pulled down to the shaft easily.

Another important point of our procedure for the bone union of the tuberosities in an HHR is the use of a cementless stem. We routinely select cementless stems to obtain bone union, but we select a cemented stem when the prosthesis head cannot be maintained at the correct position due to severe osteoporosis. Two types of third-generation shoulder prostheses (the Bigliani-

Table 4 Studies reporting outcomes after hemiarthroplasty

Author	Year	Patients	Stem	Cement fixation	Bone union rate (%)	Constant-Murley score	Forward elevation (degrees)
Loew [15]	2006	39	Aequalis	NA	56	52	92
Amirfeyz and Sarangi [16]	2008	39	NA	Cemented	87	NA	133
Kontakis [17]	2009	28	Aequalis	Cemented	NA	68	149
Castricini [18]	2011	57	Aequalis TESS	Cemented	73	59	NA
Krishnan [19]	2011	112	Aequalis	Cemented	88	NA	130
Shah [20]	2011	32	Comprehensive	Cemented	NA	NA	85
Noyes [30]	2011	22	Bigiliani Flatow Equinoxe	Cemented	60	50	86
Boons [21]	2012	24	Global	Cemented	NA	64	98
Cuff and Pupello [22]	2013	23	Aequalis Foundation	NA	61	NA	100
Boileau [29]	2013	30	Aequalis	Cemented	87	68	136
Baudi [23]	2014	25	Aequalis Gerber SMR	NA	40	46	89
Bonneviaalle [24]	2016	57	NA	NA	80	54	112
Hoel [25]	2016	35	Aequalis	NA	31	44	70
Valenti [26]	2017	51	Arrow	Cemented	75	50	98
Park [27]	2017	29	Aequalis	Cemented	93	NA	125
White [28]	2017	26	Anatomical	Both	46	34	60
Our study	2018	26	Bigiliani Flatow Global Advantage	Cementless	88	58	126

NA, not available.

Flatow and the Global Advantage) and a fourth-generation shoulder prosthesis (Global Unite) were used in this patient series. There were no significant differences in clinical results or the bone union rate among these prostheses. We used a cement stem for three cases, and two of them achieved bone union; the other did not. We suspect that cement fixation may block the blood supply from cancellous bone around the tuberosities and may have a negative effect on tuberosity healing. It is generally accepted that the humeral stem can be fixed with cement to obtain rotational stability and proper positioning [31]. However, a theoretical advantage of the uncemented humeral stem is that it does not further compromise the blood supply of the metaphysis due to the heat generated by bone cement [32].

White *et al.* investigated the outcomes of the use of a cementless humeral stem for proximal humeral fractures, and they reported that the mean Constant-Murley score was 34 points [28]. Pijlis *et al.* evaluated a consecutive series of proximally porous-coated hemiarthroplasties for the treatment of severe proximal humeral fractures. The mean Constant-Murley score was 68 points, and they observed no cases of radiographic tilting or subsidence [32]. In their series with cementless humeral stems, even when poor bone conditions were present, good fixation without loosening was achieved. Pijlis *et al.* also stated that sufficient rotational stability can be provided around the humeral stem, once bone ingrowth has occurred [32, 33].

The reported average distance between the top of the prosthesis head and the top of the pectoralis major tendon was 56 mm [34]. As noted above in the 'Surgical technique' section, we set the top of the humeral head approx. 40 mm above the proximal attachment of the pectoralis major tendon when considering the height of a cementless stem. As a result, the total length of the humerus becomes shorter than normal by approx. 1 cm because of the overlapped reduction.

The use of cable wire fixation might be beneficial for the union of the tuberosities. We used cable wire for stronger fixation of the tuberosities. If a tuberosity fragment was too small or thin for drilling holes, cable wire was passed through the insertion of the rotator cuff. We previously used nonabsorbable sutures for the fixation of tuberosities before 2004, but the clinical results were worse than those obtained with cable wires due to the lesser stability of the bone fragments [35]. From 2004, we have used cable wire for stronger tuberosity fixation. Krause *et al.* reported that in hemiarthroplasty for proximal humeral fractures, the reattachment of the tuberosities with cable wire and bone grafting gives consistently better radiographic and functional results than with suture fixation alone [36].

Dietz *et al.* reported that the use of an encircling steel cable for the fixation of tuberosities results in a significantly higher anatomical healing rate and higher absolute Constant-Murley scores compared to suture fixation [37]. Knierzinger *et al.* evaluated the strength of the reattached tuberosities in reverse total shoulder arthroplasty fixed with cables or with sutures in a cerclage-like technique [38]. They reported that tuberosities reattached with cable wire showed higher fixation strength and less rotation compared to suture fixation. It has also been reported that cable wire fixation resulted in a lower bone absorption rate than suture fixation in HHR [36, 39].

However, regular steel wires sometimes break, migrate, and cause symptoms with bursal accumulation, and they may cause metallosis due to metal-on-metal contact with holes of the prosthesis [3, 18, 40]. In our present study, bone absorption caused by the metallosis was not observed. Breakage of the cable wires occurred in four cases, but the breakage occurred after bone unions. The patients have not complained of any pain due to wire breakage as of this writing, but careful and longer follow-up is needed.

For postoperative rehabilitation, the reported regimens are rather longer than our protocol, and only passive ROM exercises are permitted for the first 6 weeks, with active assisted ROM exercise starting at 6 weeks if tuberosity healing is evident radiographically. At our institute, we have been starting patients on early passive ROM exercise 1 day after surgery and active ROM starting 3 weeks postoperatively, which might contribute to the achievement of a good post-operative range of motion. Our post-operative rehabilitation program was not related to the failure of bone union.

We have found no report in the English literature about the clinical or radiographic results of HHRs for severe proximal humeral fractures among the fracture types. It might be easier to reduce the tuberosity to the shaft in a 3-part fracture than in a 4-part fracture. In the present study, there was no significant difference between the 3-part and 4-part groups in the bone union rate and clinical outcomes. This is probably because the greater and lesser tuberosity fragments in the 4-part group were large enough for reduction, and no special effort was required in our patients.

Our study has some limitations. It was retrospective and not randomized. A randomized controlled trial with a larger number of patients is needed. Second, the assessment of bone union is ambiguous because not all patients underwent computer tomography (CT) scans. Using the radiographs, we defined bone healing as the presence of dense bone structures between the tuberosities and humeral shaft, with no tuberosity detachment, migration, or nonunion. However, the reliability of this technique might be inferior to that of CT evaluations.

In conclusion, various approaches have been used to achieve bone union of the tuberosities. The tuberosity-overlapping technique using cable wire and a cementless stem might be beneficial for tuberosity union. Our present analyses revealed that the bone union rate and clinical outcomes were comparable compared with the reported results of the conventional anatomical reduction technique for bone fragments.

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