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Modified Hook Wiring Technique for Greater Tuberosity Fractures: A Prospective Study

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Managing greater tuberosity (GT) fractures, especially those with glenohumeral (GH) dislocations, poses a challenge in balancing stable fixation while promoting early mobilization. While surgical fixation is often required for significant displacement, the optimal fixation technique remains debated due to the risk of complications and inconsistent outcomes. This study aimed to evaluate the outcomes of the Modified Hook Wiring (MHW) technique for open reduction and internal fixation of isolated displaced GT fractures. Thirteen patients with a mean age of 49.4±4.7 years were treated using the MHW technique, with 84.6% presenting concomitant GH dislocations. The mean follow-up was 16±3.3 months. The functional evaluation using the Constant-Murley and ASES scores yielded averages of 77.9±16.9 and 83.1±19.6 at one year, with no relevant changes at the final follow-up. The average range of motion showed forward flexion of 148°±31° and abduction of 142.3°±26.2°. The mean subjective shoulder value reached 81.5%±13.6%, while the mean visual analog scale score was 1.46±1.7. Radiographic analysis confirmed complete fracture healing in all cases by 9.7±1.3 weeks, with no evidence of displacement or malunion. Two patients (15.3%) experienced postoperative stiffness, and one developed a superficial wound infection. The results suggest that the MHW technique offers stable fixation, reliable union, and satisfactory shoulder function, making it a promising alternative for treating displaced GT fractures, particularly in the setting of GH dislocation. Its facilitation of early shoulder mobilization and low complication profile highlight potential benefits over conventional fixation methods. This study provides Level IV evidence. Trial registration: NCT05403879.

Keywords: Greater tuberosity fractures, Modified Hook Wiring, Shoulder fractures, Shoulder stiffness.

INTRODUCTION

Greater tuberosity (GT) fractures are more commonly seen in young adults with good bone quality following high-energy trauma[1]. They account for 14–20% of proximal humeral fractures (PHFs) and occur more commonly in men[2,3]. Among these, 5% to 57% result from a glenohumeral (GH) dislocation, whereas 15% to 30% of all anterior GH dislocations result in GT fracture[4]. Most GT fractures are minimally displaced and can be effectively managed non-operatively. However, displaced fractures tend to migrate posteriorly and superiorly due to the traction from the rotator cuff (RC)[4].

Surgical fixation is typically indicated for displaced GT fractures with more than 5 mm of displacement (5%–15% of cases), as non-operative treatment in such cases often leads to suboptimal outcomes due to compromised RC biomechanics and the development of subacromial impingement[2]. Various surgical techniques have been proposed for GT fixation, including open reduction and internal fixation (ORIF), percutaneous (PC) fixation, and arthroscopic or arthroscopic assisted approaches[5]. These procedures utilize different devices, such as suture anchors, trans-osseous sutures[6], tension bands[7], and plates or screws[8]. While clinical outcomes across these techniques are generally comparable, no method has been free of complications. Reported postoperative complications include implant failure, stiffness, impingement, re-displacement, and GT resorption, which have been observed with the use of different fixation devices[9]. Consequently, the ideal fixation technique for displaced isolated GT fractures remains uncertain.

We hypothesized that the Modified Hook Wiring (MHW) technique could reduce these complications by providing stable fixation and enabling early mobilization. This study presents the early clinical and radiological outcomes of using the MHW technique for ORIF in isolated displaced GT fractures, with a minimum follow-up of one year, and reports any associated complications.

PATIENTS AND METHODS

This study has been approved by the ethics committee of the authors' institution. The investigation was conducted and reported in accordance with the STROBE guidelines. All patients were thoroughly informed about the details of the MHW technique, including its potential benefits and risks. Additionally, they were made aware of alternative treatment options, including conservative management and surgical alternatives such as percutaneous screw fixation or ORIF with screws or plates. The treatment and follow-up period for all patients spanned from April 2022 to August 2024, and informed consent was obtained from each participant.

This prospective study enrolled skeletally mature patients aged 18 to 60 years who were presented with acute, isolated, and displaced GT fractures, with or without associated GH dislocations. Exclusion criteria included patients over 60 years, those with open GT fractures, pathological fractures, associated surgical neck humerus (SNH) fractures, or a history of previous shoulder surgeries. Sixteen patients were initially included for MHW ORIF, but two were excluded due to intraoperative iatrogenic fractures of the GT fragment, both of whom were treated with tension band wiring. Additionally, one patient died two months post-surgery and was excluded from the study. The patient enrollment process is detailed in Fig. 1.

All patients presenting with isolated displaced GT fractures between 2022 and 2023 and meeting the inclusion criteria were enrolled in this investigation. Due to the exploratory nature of the study, a formal sample size calculation was not performed. Instead, the sample size was determined by the number of eligible patients available during the study period. A total of 13 patients with displaced GT fractures underwent ORIF using the MHW technique at our institution. The mean age of the patients was 49.38±4.7 years (range: 37-56 years), with 5 males (38.4%) and 8 females (61.5%) included in the study. Injuries involved the right shoulder in 5 cases (38.4%) and the left shoulder in 8 cases (61.5%). The injury mechanisms included road traffic accidents (38.4%), seizure-related incidents (30.7%), falls onto the shoulder (23%), and direct

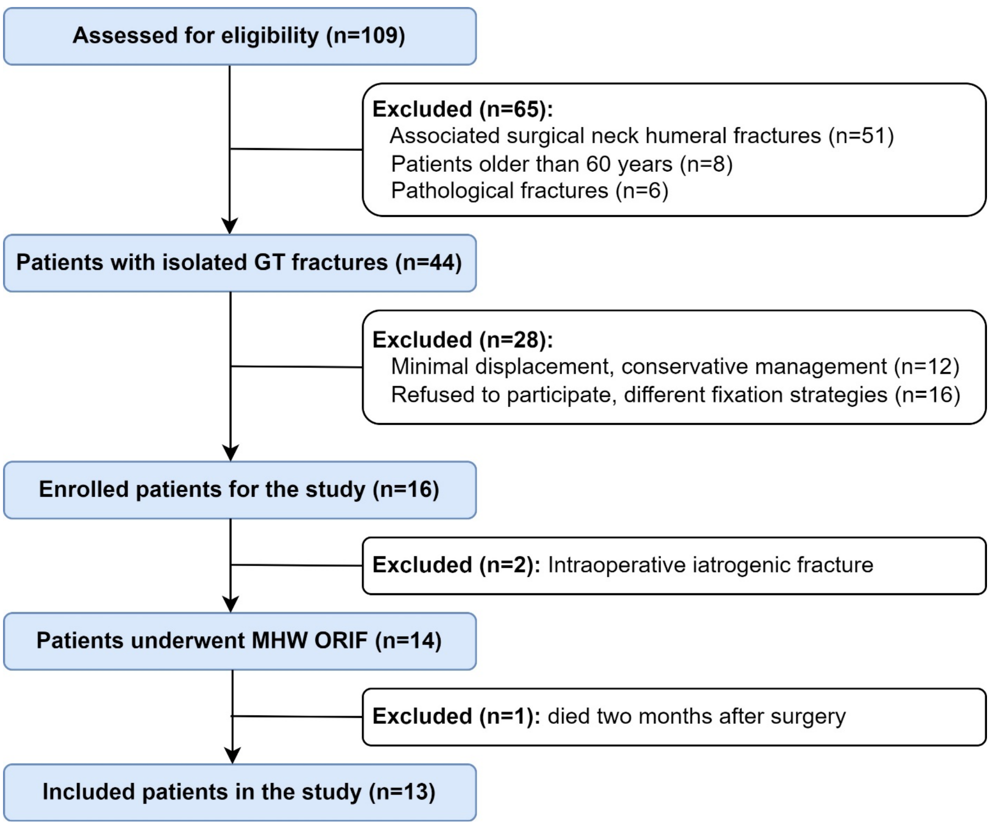

Fig. 1 — Flowchart for patient enrollment process.

trauma (7.6%). Eleven patients (84.6%) had associated GH dislocations, which were reduced intraoperatively under sedation within two hours after emergency presentation. Joint reduction was confirmed via fluoroscopy. Radiological assessments, including shoulder radiographs and computed tomography (CT) scans (Fig. 2a, 2b), were performed for all patients to confirm the diagnosis and rule out any associated PHFs. Table I provides a detailed overview of patient demographics.

Surgical procedure

Patients were positioned in a beach chair position under general anesthesia. Using the deltopectoral approach (DP-A), the fracture site was exposed and visualized. The GT was manually or with a blunt instrument pressed anteriorly and downward into its anatomical position, based on the anterior fracture line, ensuring that no soft tissue was interposed in the fracture site. For temporary stabilization, a 2mm Kirschner wire (K-wire) was advanced through the GT into the humeral head, maintaining the reduction, which was confirmed visually and with fluoroscopy (Fig. 2c).

For most patients, the MHW fixation device (Fig. 3a) was prepared the day before surgery. A 2.5mm K-wire was shaped to replicate the natural contours of the GT and proximal humerus (PH)[10]. As illustrated in Fig. 3b, the wire was bent three times using pliers: the first bend created two equal parallel halves, the second was a 13° bend 2cm from the first, mimicking the lateral angle of the PH[10], and the third bend, 4.5cm from the second, created a 60° angle, resembling the normal distance from the GT to the PH's angular point[10]. A smooth contour was formed between the second and third bends to mirror the GT. Two limbs were then created: a 6.5cm vertical limb and a horizontal limb, shortened to 4cm by trimming the excess with K-wire

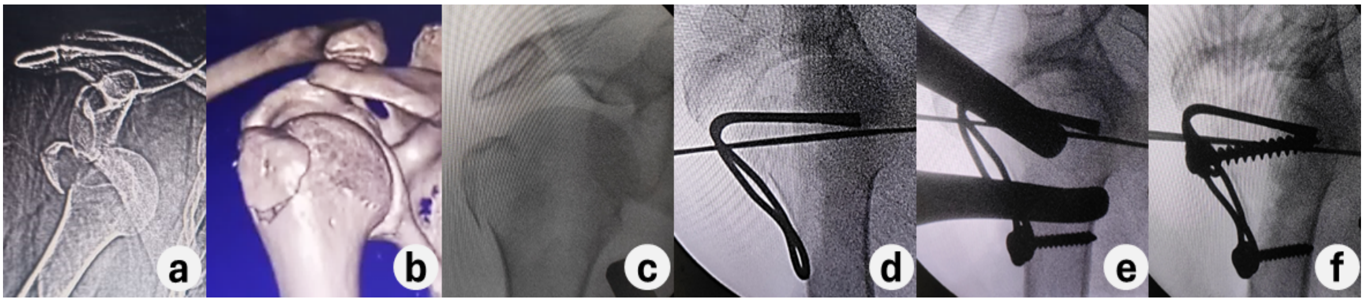

Fig. 2 — (a) AP shoulder radiograph showing GT fracture associated with anterior GH dislocation; (b) Post reduction 3D CT reformat confirming reduction and excluding concomitant fractures; (c) Intraoperative fluoroscopic image showing reduction of GT; (d) Temporary fixation with K-wire and insertion of the horizontal limb of MHW device after predrilling; (e) Insertion of a bi-cortical distal screw of appropriate length into the humeral shaft in eccentric position via the inferior oblong hole of the device; (f) Insertion of a fully cancellous superior screw of appropriate length through the superior oblong hole to fix the GT anatomically.

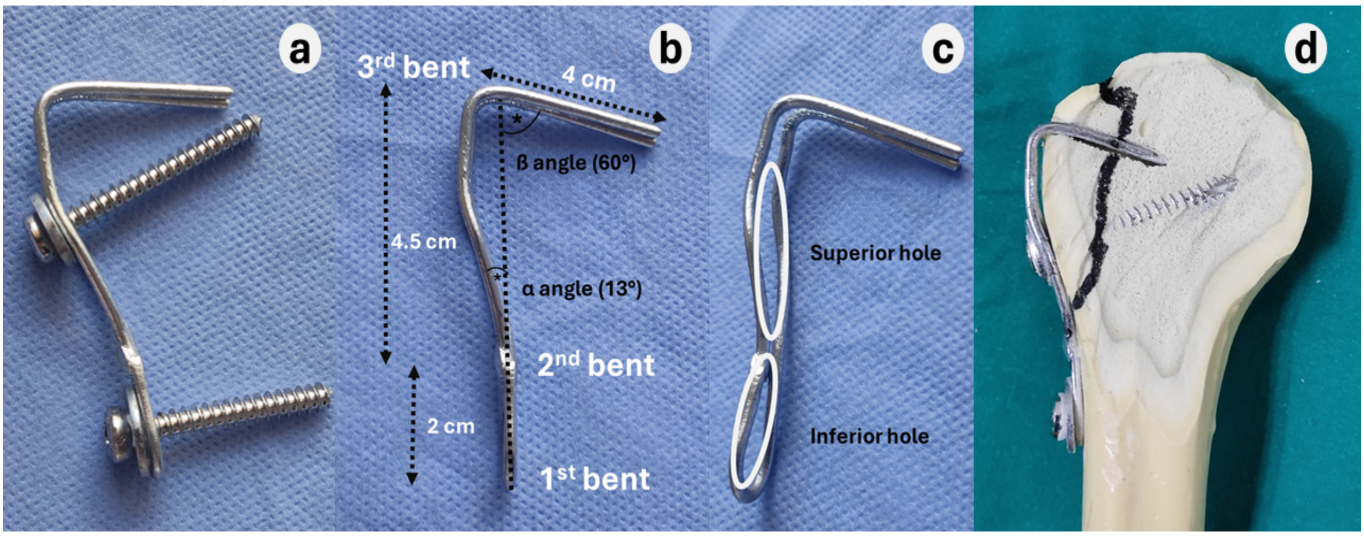

Fig. 3 — a) Photograph of the MHW fixation device; (b) Front view of device showing the three bents and angles between transverse and vertical limbs; (c) Side view showing the two oblong openings for screw placement; (d) Bone model with anterior osteotomy of the humeral head, demonstrating final positioning of the MHW device and anatomical reduction of the GT.

Table I. — Patient demographics and clinical outcomes following the MHW technique for fixation of isolated GT fractures.

Patient No.	Age	Gender	Occu-pation	Mode of trauma	Side	Asso-ciated disloca-tion	Concomitant injuries	Trauma surgery interval (days)	Follow-up period (months)	Surgery to reha-bilitation interval (weeks)	Radio-graphic healing time (weeks)	VAS	ASES score	CM score		SSV Score (%)	Abd (°) ROM	FF (°) ROM	IR (°) ROM	ER (°) ROM	Abd strength (N)	Abd strength ratio (%)	Complications
1	37	M	Farmer	RTA	Lt	Y	TP fracture	2	23	8	7	0	98.3	98	Excellent	90	160	155	65	80	168	92.3	-
2	52	F	HW	Seizures	Lt	Y	-	6	20	10	9	1	88.3	79	Good	90	160	160	68	78	100	80.6	-
3	50	F	HW	Seizures	Rt	Y	-	6	16	12	11	0	94.9	83	Good	80	150	150	60	70	105	90.5	Superficial wound infection
4	49	M	Farmer	Direct trauma	Lt	-	-	5	19	10	9	2	84.9	89	Excellent	90	150	160	65	68	172	93.9	-
5	46	F	HW	RTA	Rt	Y	Acetabulum and rib fractures	7	13	18	10	5	38.3	40	Poor	50	80	79	36	50	110	92.4	Stiffness
6	48	F	HW	Fall	Lt	Y	-	4	18	11	10	1	95	84	Good	70	150	165	70	70	115	93.4	-
7	56	M	Farmer	RTA	Lt	Y	-	3	14	12	10	0	94.9	94	Excellent	90	160	165	59	65	162	91.01	-
8	50	M	Engineer	RTA	Rt	Y	Clavicle fracture	4	18	13	11	1	91.6	86	Excellent	95	150	170	70	70	170	95.5	-
9	49	F	HW	Seizures	Lt	-	-	4	13	10	8	0	96.6	90	Excellent	90	150	160	65	72	108	90	-
10	53	F	Teacher	Fall	Rt	Y	-	2	15	14	12	0	98.3	87	Excellent	90	160	170	65	80	102	85.7	-
11	48	F	HW	Seizures	Lt	Y	-	4	14	12	10	2	88.3	86	Excellent	85	150	150	58	74	100	82.6	-
12	55	M	SJ	RTA	Rt	Y	Distal femur fracture	6	12	20	11	5	41.7	45	Poor	60	90	80	50	56	165	92.1	Stiffness
13	49	F	HW	Fall	Lt	Y	-	4	13	10	9	2	86.6	80	Good	80	140	160	70	66	113	89.6	-

M: Male, F: Female, Rt.: Right, Lt; Left, HW: Housewife, SJ: Sales jobs, Y: Yes, RTA: Road traffic accident, TP: Tibial plateau, VAS: visual analogue scale, ASES: American Shoulder and Elbow Surgeons, CM: Constant-Murley, SSV: sub¬-jective shoulder value, ROM: range of motion, FF: forward flexion, Abd: abduction, IR: internal rotation, ER: external rotation, N: newton.

cutting forceps. Two oblong holes were made along the vertical limb (Fig. 3c): the proximal hole 1.5-2cm distal to the third bend, and the distal hole at the lowest point of the vertical limb.

After the fracture was temporarily fixed, a 2.5mm K-wire was drilled into the center of the GT fragment, 8mm below its upper surface, angled at 30° downward. A second hole was drilled adjacent to the first, forming a 5 mm-wide opening to accommodate the horizontal limb of the MHW device. The horizontal limb was then manually inserted and pushed medially through the transverse hole into the humeral head, while the vertical limb seated and supported the GT laterally, ensuring stable reduction. The final position of the device was confirmed with fluoroscopy, ensuring that the humeral articular surface remained intact (Fig. 2d). In two cases, the GT fragment fractured longitudinally during device insertion, and those patients were treated with tension band wiring and subsequently excluded from the study.

A 4.5mm bi-cortical screw of appropriate length, with a washer, was then eccentrically inserted into the distal hole (Fig. 2e), followed by a 6.5mm uni-cortical cancellous screw into the proximal oblong hole, traversing the GT and into the humeral head (Fig. 2f). Fluoroscopy confirmed the correct GT reduction and appropriate screw lengths. The screws were tightened alternately to secure fixation. Non-absorbable Ethibond sutures (number 5) were used to repair concomitant partial rotator cuff tears (RCTs) in three patients (23%) and biceps tendon injury (BTI) in one patient (7.6%). Final fluoroscopy confirmed adequate reduction and construct stability in multiple projections, including flexion, internal, and external rotations (IR, ER) (Fig. 4). Hemostasis was achieved, the DP fascia was closed, and the wound was closed in layers.

Postoperative care

A shoulder abduction pillow was worn for six weeks post-surgery. The sutures were removed two weeks after the operation. Passive range of motion (ROM) exercises were initiated at the start of the second week, with active ROM exercises beginning after six weeks, once the shoulder pillow was discontinued. A structured rehabilitation program focused on muscle strengthening and ROM improvement was recommended for all patients, overseen by a specialized shoulder physiotherapist. Clinical and radiographic evaluations were conducted every three weeks. Patients were allowed to return to work once radiographic evidence of fracture union was confirmed.

Postoperative evaluation

Clinical assessments were conducted at both the one-year follow-up and the final visit. These evaluations included active ROM measurements, functional scores including the Constant-Murley (CM)[11], American Shoulder and Elbow Surgeons (ASES)[12], and Subjective Shoulder Value (SSV)[13] scores. Pain levels were recorded using the Visual Analog Scale (VAS)[14]. Shoulder abduction strength was measured in newtons (N) using the microFET®2TM digital handheld dynamometer (HOGGAN Industries, Inc, West Jordan, UT, USA), and compared to the contralateral shoulder. Fracture healing was monitored through serial radiographs, with healing time defined as the point when cortical continuity was visible in one of three radiographic planes (AP, ER, or IR) and when local tenderness resolved[15]. Two independent orthopedic surgeons with level 3 experience, along with a musculoskeletal radiologist, confirmed fracture healing. Gillespie et al. defined an anatomical reduction of the GT based on the GT-Humeral Head (HH) distance, which should be 4-10 mm at the final follow-up. Loss of GT reduction was identified by >3mm displacement in final radiographs compared to immediate postoperative imaging[16,17].

Statistical analysis

Statistical analysis was conducted using. IBM SPSS Statistics for Windows, Version 29.0.2.0 (IBM Corp. Released 2023, Armonk, NY). Qualitative data was

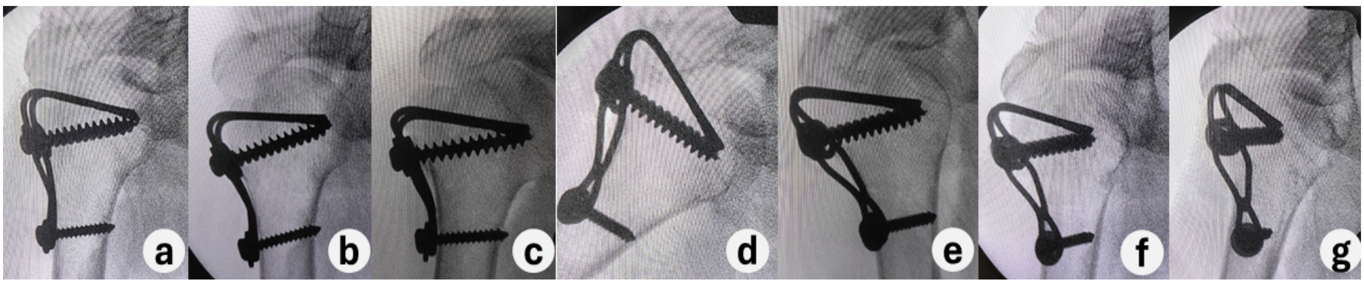

Fig. 4 — (a through g) Intraoperative fluoroscopic views following fixation of the GT, including cephalic, caudal, internal rotation, external rotation, and lateral projections to confirm reduction and fixation.

described using number and percentage. Quantitative data was described using median (minimum and maximum) for non-parametric data and mean, and standard deviation (SD) for parametric data. Data was tested for normality using the Kolmogorov-Smirnov Test. Comparing two independent groups with normally distributed data was utilized using the T-test. The Man-Witney-U test was used to compare two independent groups with abnormally distributed data. Statistical significance was set at $p < 0.05$.

RESULTS

In this study, 11 patients (84.6%) were presented with GT fractures accompanied by GH dislocation, all of which were successfully reduced under sedation within two hours of the injury. Six patients (46.1%) had a prior history of GH instability, which had been treated conservatively without surgery. All patients underwent ORIF using the MHW technique within an average of 4.3±1.5 days post-injury (range: 2-7 days). Postoperative rehabilitation was initiated after a mean of 12.3±3.3 weeks (range: 8-20 weeks), with four patients (30.7%) showing poor compliance with physiotherapy.

The mean follow-up period was 16±3.3 months (range: 12-23 months). At the one-year mark, the mean CM and ASES scores were 77.92±16.9 and 83.14±19.6, respectively. Slight improvements were observed at the final follow-up, with CM and ASES scores averaging 80.07±17.4 (P=0.53) and 84.43±20.2 (P=0.49), though these changes were not statistically significant. Shoulder ROM at one year showed FF of 140.4°, abduction of 135.3°, IR of 59.3°, and ER of 66°. By the final visit, these values had marginally increased to 148°, 142.3°, 61.6°, and 69.1°, respectively, with no statistically significant differences (P=0.06, 0.08, 0.27, and 0.31, respectively). The final SSV was 81.5±13.6% of the contralateral side (range: 50%-95%), while the mean VAS score was 1.46±1.7 (range: 0-5). Shoulder abduction strength averaged 130±31.1N (range: 100-172N), which demonstrated 90±4.4% (range: 80.6%-95.5%) of the strength of the contralateral shoulder, with a mean difference of 13.69±4.83N between the injured and uninjured shoulders. All patients achieved fracture healing of the GT with an average time of 9.7±1.3 weeks (range: 7-12 weeks), and anatomical reduction was confirmed in all cases without any displacement (Fig. 5).

Two patients (15.3%) developed shoulder stiffness and were scheduled for implant removal and adhesiolysis. Despite undergoing rehabilitation, both patients started the program 18-20 weeks after surgery due to extended hospital stays, including time in the intensive care unit (ICU), awaiting surgical intervention for other injuries, such as pelvic and femoral fractures. Another patient (7.6%) developed a superficial wound infection, which was successfully treated with wound care and antibiotics. No cases of malunion, delayed union, or implant-related complications were reported. Detailed clinical and radiological data for all patients are presented in Table I.

DISCUSSION

The optimal surgical approach for managing displaced GT fractures remains a topic of debate. Various techniques, including arthroscopic, PC, and ORIF, have been reported in the literature. A wide array of fixation devices, such as plates, sutures, and screws, have been utilized. Previous studies have employed different types of plates, including pre-contoured locked plates, standard locked plates, and intraoperatively contourable low-profile plates. Each of these approaches, however, presents unique challenges and potential complications[9]. In this prospective study, we introduced the MHW technique for the fixation of isolated displaced GT fractures.

GT fractures are often associated with soft tissue damage, GH dislocation, or brachial plexus injury

Fig. 5 — (a, b) Follow-up shoulder radiographs (19 months postoperatively) of a 49-year-old patient showing anatomical fixation with complete healing of the GT using the MHW technique; (c, d, e) Clinical photographs showing shoulder abduction, forward flexion, and external rotation range of motion at follow-up.

(BPI)[7,15,18-26]. In this study, 84.6% of patients had concomitant GH dislocation. Similarly, a recent meta-analysis[22] reported a 33.9% incidence of associated dislocation across fourteen previous studies[5-8,15,20-22,24-29]. The literature has also indicated a 5.8% incidence of BPI, which can adversely affect patient outcomes[5,9,18,22,25,27,30]. Fortunately, none of the patients in our study were presented with BPI. Kumar et al. in their meta-analysis[22] reported RCTs in 24.8%[5,7,15,18,18-22,24-26], BTIs in 5.5%, and Bankart lesions in 2.6% of patients[5,7,15,18-26]. These injuries have been documented in varying percentages across studies employing ORIF or arthroscopic techniques. In our study, RCTs and BPIs were observed in 23% and 7.6% of cases, respectively.

The DP-A was preferred over the deltoid-splitting approach (DS-A). This approach allowed secure placement of our MHW device on the humeral shaft without risking the axillary nerve, which is a concern with the DS-A when extended distally (5cm inferior to acromion process). Our fixation device's vertical limb measured 6.5 cm, and we did not need to create a double window by splitting the deltoid muscle around the axillary nerve. The DP-A has been favored in previous studies, particularly with the use of standard locked plates[16,31-34]. However, some studies have reported that inferior dissection is unnecessary with the DS-A when low-profile plates[19-22,27,33], screws, or sutures are used. Another benefit of the DP-A is that it preserves the deltoid muscle's attachment to the acromion and appropriate exposure for the RC, allowing for management of concurrent RCTs or BTIs. Although arthroscopic procedures can effectively address such injuries, they are associated with a risk of GT absorption[9], a complication we did not encounter with our method. While no evidence exists comparing postoperative abduction strength between the DP-A and DS-A, patients in our study reported satisfaction with shoulder strength, as indicated by a mean abduction strength of 90±4.4% compared to the contralateral shoulder.

In most cases, the MHW device was assembled the evening before surgery to facilitate more precise contouring of the K-wire for better adaptation to the GT. This approach was intended to reduce intraoperative time. Although this practice deviates from standard protocols concerning implant manufacturing, sterilization, and Medical Device Regulations (MDR), the device preparation was conducted under sterile conditions to minimize the risk of contamination. Following assembly, the devices were subjected to a thorough sterilization process. Despite these precautions, the expected intraoperative time savings were minimal, leading us to recommend performing the contouring step intraoperatively. Notably, no postoperative deep-site infections occurred among our patients.

The clinical outcomes observed were favorable. At the final follow-up, 84.6% of patients (n=11) achieved excellent or good results, with a mean CM-S of 80±17.4 (range: 40-98). This outcome was comparable or superior to studies using PC[7,28,30], ORIF[7,18,22,30], or arthroscopic[15] fixation methods, although some studies reported higher CM-S[20,21,31,35,36]. The average ASES score, in our study was 84±20 (range:38.8-98.3), close to earlier reports with ORIF [34] and arthroscopic fixation strategies[5,23,26]. However, it was lower than other reports utilizing open[31,37] and arthroscopic techniques[25,29,34,36]. In terms of pain, the mean VAS score was 1.46±1.7 (range: 0-5), which aligned with reports from earlier studies[5,23,25,31,37]. Notably, our pain levels were lower than those reported by Platzer et al.[7] and Choi et al. [15], who demonstrated mean scores of 4.8 and 2.18, respectively.

At the last visit of this study's participants, the average FF ROM was 148°±31° (range: 79°-170°), that was close or even better than most earlier studies[5,16,21,26,28-30,32,34,36,37]. However, Dimakopoulos et al.[18], Choi et al.[15], and Jang et al.[23] demonstrated relatively better mean ranges of 170°, 173°, and 167.8°, respectively. Similarly, the mean abduction ROM in our study was 141°±26.2° (range: 80°-160°), that was better than findings reported with Plachel et al.[32], Liao et al.[34], and Park et al.[26]. Nevertheless, Dussing et al. and Li et al. demonstrated better mean ranges of 150° and 158.6°, respectively. In a similar vein, the mean rotational ROM of study's participants, was higher than different studies[5,6,18,23,26,28-30,37]. In our investigations, eleven patients (84.6%) were satisfied at the last follow-up visit, with resuming their occupational tasks, with a mean SSV score of 81.5±13.6%. Tables II and III demonstrate detailed patient demographics, clinical and radiological findings, that utilized either the ORIF[7,8,16,18-22,27,30-33,37], the PC fixation[1,7,8,28,30], or the arthroscopic/arthroscopic assisted fixation[5,23,24,26,35,36,38].

An average healing time less than 12 weeks was reported in most earlier reports[5,15,16,18,21-23,25-27,29,31,34,35,37]. Similarly, our study demonstrated a mean healing time of 9.7 ± 1.3 weeks (range: 7-12 weeks). On the contrary, some studies, such as that by Cheng et al., reported a longer healing time of 14 weeks

Table II. — Summary of previous studies using ORIF techniques for GT fracture fixation.

Study, year	Number (M-F)	Mean age (range)-years	FU (Mean ±SD) (range)-months	Associated dislocation (n)	Method of fixation (approach/ device)	PROs (Mean ±SD), (range)	ROM (Mean ±SD)	Radiological healing time (Mean ±SD)-weeks
Open reduction and internal fixation								
Present study	13 (5-8)	49.3 ± 4.7	16 ± 3.3	11	DP-A (MHW technique)	CM 80 ± 17.4 ASES 84.4 ± 20.2 SSV 81.5 ± 13.6% VAS 1.46±1.4	FF 148 ± 31° ABD 141 ± 26.2° ER 69 ± 9° IR 62 ± 10°	9.7 ± 1.3
Cheng[31], 2019	25 (7-18)	75 (60-88)	50.8 (22-80)	0	DP-A (plating)	CM 90.3 (80-100) ASES 90.1 (72-100) VAS 1.3 (0-2.5)	NM	14 (10-18)
Hu[22], 2018	68 (48-20)	38.1 (23-67)	30.5 (14-46)	30	DS-A (plating)	CM 86.8 (70-96)	NM	9.4 (8 -14)
Dussing[30], 2018	11	47.44 ± 17.3	60.7 ± 23.2	all	Screw, suture anchors	WOSI 373 ± 486 CM 75.1 ± 19.4 Rowe 83 ± 20	FF 151° ABD 150° ER 48°	NM
Plachel[32], 2017	6 (5-1)	60 (37-85)	59	6	DP-A (Screws or wires)	CM: 72 SST: 9.0 SSV: 72%	FF 133° ABD 138	NM
Yoon[37], 2017	29 (19-10)	56.7 (24-79)	24	NR	DS-A (Screws with Washer)	VAS 1.1 ± 1.1 SSV 93.4 ± 5.3 UCLA 31.2 ± 2.7 ASES 92.6 ± 6.7	FF 144 ± 16° ER 33 ± 11° IR 13.3 ± 1.7	<12
Bogdan[27], 2017	10 (7-3)	47.1 (23-87)	8 (3-12.5)	9	DS-A (Mesh Plate)	DASH 28.2 (±22.4)	NM	8.5
Ma[19], 2016	11 (5-6)	53.72 (38-63)	18.27 (13-26)	NR	DS-A (plating)	CM, DASH	NM	Within 12 months
Gillespie[16], 2015	11 (4-7)	60 (37-71)	21 (16-44)	0	DS-A (plating and suture)	Penn Shoulder Score 79	FF 147° ER 25°	NM
Chen[21], 2013	19 (16-3)	42 (25-66)	33.2 (24-42)	11	DS-A (modified footplate)	CM 90.6 ± 4 (77-95)	FF 155°	9.4 (8 -14)
Schöffl[20], 2011	10 (5-5)	45.6 (29-68)	> 6	1	DS-A (modified calcaneal plate)	CM 94.2 (91–98)	NM	Within 6 months
Mattyasovzsky[8] 2011	9 (NR)	58.4 (31-80)	36 (9-120)	3	DS-A (plate or screws)	CM 64 DASH 11.4	NM	NM
Platzer[7], 2008	52 (31-21)	47 (25-66)	62 (24-132)	9	DS-A (Suture or TBW)	CM 87.2 VAS 4.8 UCLA 30.6	NM	NM
Dimakopoulos[18], 2006	34 (19-15)	52.8 (18-84)	57.9 (24-120)	34	DS-A (trans-osseous sutures)	CM 88.4 (45 - 100)	FF 170° ER 55° IR T10	7-11

M-F: Male-Female, SD: standard deviation, FU: follow-up, n: number; NR: Not reported, PROs: patient reported outcomes, ROM: range of motion; DP-A: deltopectoral approach, DS-A: deltoid splitting approach, CM: Constant-Murley, SSV: sub¬jective shoulder value, VAS: visual analogue scale, ASES: American Shoulder and Elbow Surgeons, DASH: Disabilities of Arm, Shoulder and Hand score, WOSI: Western Ontario Shoulder Instability Index, UCLA: University of California at Los Angeles shoulder score, FF: Forward flexion, Abd: Abduction, IR: Internal rotation, ER: External rotation.

Table III. — Summary of previous studies using percutaneous or arthroscopic techniques for GT fracture fixation.

Study, year	Number (M-F)	Age (Mean) (range)-years	FU (Mean ±SD) (range)-months	Associated dislocation (N)	Method of fixation (Device)	PROs (Mean), (range)	ROM (Mean), (range)	Radiological healing time (Mean ±SD)-weeks
Percutaneous fixation								
Dussing[30], 2018	7 (NR)	47.44	60.7 ± 23.2	7	Screws	WOSI 373 ± 486 CM 75.1 ± 19.4 Rowe 83 ± 20.	FF 151 ABD 150 ER 48	NM
Elkady[28], 2017	12 (8-4)	46 (22-63)	18 (15-30)	4	Screws with Washers	CM 85.5	FF 140° (100-170°) ER 70.5 (45 - 85°)	NM
Platzer[7], 2008	52 (31-21)	47 (25-66)	62 (24-132)	9	Screws	CM 81.6 VSS 6.2 UCLA 29.8	NM	NM
Arthroscopic/ arthroscopic assisted fixation								
Zhang[36], 2020	15 (7-8)	48 (22-66)	38.4	15	Suture with screw	CM: 95 ASES: 95 VAS: 0.4	FF 157 ER: 40 IR: T11	8 – 14
Choi[15], 2018	13 (3-10)	59.87 (40-81)	30 (12-56)	1	Suture anchors	VAS 2.18 (0-4) UCLA 29 (27-35) CM 73 (69-100)	FF 173° (160° -180°)	11-24
Jang[23], 2018	11 (8-6)	46.5 (23-72)	22 (17-38)	NR	Suture anchors	VAS 1 (0–3) ASES 86.9 (78.3–100) KSS 88.6 (82–100)	FF 167.8° (140–180°) ER 36° (20–70°) IR T12 level	10 (7-12)
Park[26], 2015	11 (2-9)	64 (41-83)	26 (18-40)	2	Suture anchors then plating (MIPO- 5cm incision)	ASES 84 UCLA 29 SST 8	FF 138° ABD 135° ER 19° IR L2 level	6-12
Wang[35], 2012	23 (15-8)	34.8 (27-45)	20 (18-36)	NR	Screw and washer fixation	CM 92 (86-100)	NM	12 (8-24)
Ji[5], 2010	16 (11-5)	56.5 (33-82)	28.25 (18-42)	7	Suture anchors	VAS 1.2 (0 - 4) UCLA 31 (21- 35) ASES 88.1 (81.5 -100)	FF 148.7° (120° - 170°) ABD 145° (120°-170°) ER 24° (10° - 40°) IR L1 level	6-12

M-F: Male-Female, SD: standard deviation, FU: follow-up, n: number; NR: Not reported, PROs: patient reported outcomes, ROM: range of motion; MIPO: minimal invasive plate osteosynthesis, KSS: Korean Shoulder Scoring System, CM: Constant-Murley, SSV: sub¬jective shoulder value, VAS: visual analogue scale, ASES: American Shoulder and Elbow Surgeons, DASH: Disabilities of Arm, Shoulder and Hand score, WOSI: Western Ontario Shoulder Instability Index, UCLA: University of California at Los Angeles shoulder score, FF: Forward flexion, Abd: Abduction, IR: Internal rotation, ER: External rotation.

(range: 10-18weeks) with GT fracture platting [31]. The maximum healing time in our study (12 weeks) was shorter than in many reports using ORIF[19,21,22,31] or arthroscopic techniques[23,35,36,38]. We believe the notable healing time and high union rate observed in our study can be attributed to the MHW technique's efficacy to provide rigid and stable anatomical fixation via several mechanisms. Firstly, it effectively countered the superiorly directed force exerted by the RC muscles on the GT, thereby maintaining the precise GT reduction throughout the healing process. Additionally, the technique provided a buttressing effect on the GT fragment via the device's vertical limb and the occupying inferior screw with its washer, as well as ensuring compression stability via the proximal screw and its washer. Rotational stability could be also achieved because of the previously mentioned combined factors. Furthermore, the versatility of the MHW technique allows it to be adapted for various fracture patterns, including distal radius fractures and medial malleolar fractures. While our results are promising, larger and longer-term studies are needed to further validate this technique.

The MHW technique presents a cost-effective alternative to conventional locking plate osteosynthesis for GT fractures. When comparing implant costs based on the hospital's resources, it was found that the total cost of the MHW device (comprising K-wires, screws, and washers) is up to 90% lower than that of conventional locking plates. This price difference pertains solely to implant costs, excluding additional expenses related to the operation, healthcare processes, and personnel. These findings align with previous studies comparing the costs of various management options for PHFs[39,40]. The MHW technique is particularly beneficial in healthcare settings with limited budgets, offering affordable effective treatment with promising clinical outcomes.

As an important consideration in this study, two patients (15.3%) in this study developed shoulder stiffness, despite achieving full fracture healing. Previous studies have linked all fixation devices (screws, plates, sutures, and suture anchors) to postoperative stiffness[9]. In our study, stiffness was likely due to extended hospital stays and delayed rehabilitation following the high energy trauma and its associated injuries (pelvic, distal femoral fractures, or the resultant soft tissue compromise). Close monitoring, early rehabilitation, and tailored ROM exercises should be prioritized for patients at risk of stiffness, particularly those with prolonged hospital stays. Among most patients, the MHW technique promoted early mobilization and enabled the initiation of a physiotherapy program at an earlier stage. This approach led to the restoration of shoulder mobility, with patients reporting high levels of satisfaction regarding their ROMs and overall shoulder function.

This study has several strengths, including its prospective design, a reasonable sample size given the incidence of this injury (14% of PHFs[3]), and the use of validated clinical and radiographic parameters. However, there are limitations to consider. The relatively small sample size may limit the generalizability of our findings, and a larger cohort would yield more robust data. Additionally, the follow-up period, though sufficient for assessing early outcomes, may not capture long-term complications such as late-onset shoulder stiffness or implant-related issues. Lastly, the absence of a control group precludes direct comparison of the MHW technique's efficacy with other fixation methods.

Several confounding factors could have influenced our results, including variability in patient compliance with rehabilitation protocols -as evidenced by the 30.7% non-compliance rate- and differences in the timing of surgery (ranging from two to seven days). The presence of concomitant injuries, such as RCTs or BTIs, may have affected recovery outcomes. Additionally, variations in the mechanism of injury, from high-energy trauma to low-energy falls, could have influenced the healing process and potentially skewing the results.

CONCLUSION

The MHW technique yielded favorable clinical and radiological outcomes for the fixation of displaced GT fractures, with a relatively low complication rate. It provided stable fixation, allowed early mobilization, and resulted in satisfactory functional recovery for most patients. However, further research with larger sample sizes and longer follow-up is needed to validate these results and compare the MHW technique with alternative fixation strategies.

REFERENCES

1. Sheehan SE, Gaviola G, Sacks A, Gordon R, Shi LL, Smith SE. Traumatic shoulder injuries: a force mechanism analysis of complex injuries to the shoulder girdle and proximal humerus. AJR Am J Roentgenol. 2013;201(3):W409-24.

2. Gruson KI, Ruchelsman DE, Tejwani NC. Isolated tuberosity fractures of the proximal humeral: current concepts. Injury. 2008;39(3):284-98.
3. Saleem J, Guevel B, Gillott E, Mitchell C, Widjono A, Qavi A, et al. Radiological analysis and outcomes of isolated greater tuberosity fracture-dislocations. The Annals of The Royal College of Surgeons of England. 2023;106(3):270-6.
4. Robinson CM, Shur N, Sharpe T, Ray A, Murray IR. Injuries associated with traumatic anterior glenohumeral dislocations. J Bone Joint Surg Am. 2012;94(1):18-26.
5. Ji JH, Shafi M, Song IS, Kim YY, McFarland EG, Moon CY. Arthroscopic fixation technique for comminuted, displaced greater tuberosity fracture. Arthroscopy. 2010;26(5):600-9.
6. Flatow EL, Cuomo F, Maday MG, Miller SR, McIlveen SJ, Bigliani LU. Open reduction and internal fixation of two-part displaced fractures of the greater tuberosity of the proximal part of the humerus. J Bone Joint Surg Am. 1991;73(8):1213-8.
7. Platzer P, Thalhammer G, Oberleitner G, Kutscha-Lissberg F, Wieland T, Vecsei V, et al. Displaced fractures of the greater tuberosity: a comparison of operative and nonoperative treatment. J Trauma. 2008;65(4):843-8.
8. Mattyasovszky SG, Burkhart KJ, Ahlers C, Proschek D, Dietz SO, Becker I, et al. Isolated fractures of the greater tuberosity of the proximal humerus: a long-term retrospective study of 30 patients. Acta Orthop. 2011;82(6):714-20.
9. Kumar S, Mishra A, Singh H, Clark D, Espag M, Tambe A. Surgical fixation of isolated greater tuberosity fractures of the humerus- systematic review and meta-analysis. J Clin Orthop Trauma. 2021;23:101670.
10. Kim H, Chung YG, Jang JS, Kim Y, Park SB, Song HS. Why locking plates for the proximal humerus do not fit well. Arch Orthop Trauma Surg. 2022;142(2):219-26.
11. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res. 1987(214):160-4.
12. Michener LA, McClure PW, Sennett BJ. American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, patient self-report section: reliability, validity, and responsiveness. J Shoulder Elbow Surg. 2002;11(6):587-94.
13. Gilbart MK, Gerber C. Comparison of the subjective shoulder value and the Constant score. J Shoulder Elbow Surg. 2007;16(6):717-21.
14. Johnson EW. Visual analog scale (VAS). Am J Phys Med Rehabil. 2001;80(10):717.
15. Choi S, Son I, Hyun MJ, Bae JH, Kang H. Arthroscopic treatment of greater tuberosity fractures : retrospective review of clinical and radiological outcomes. Acta Orthop Belg. 2018;84(1):47-53.
16. Gillespie RJ, Johnston PS, Gordon VA, Ward PJ, Getz CL. Using Plate Osteosynthesis to Treat Isolated Greater Tuberosity Fractures. Am J Orthop (Belle Mead NJ). 2015;44(8):E248-51.
17. Lee KR, Bae KC, Yon CJ, Cho CH. Hook Plate Fixation for Isolated Greater Tuberosity Fractures of the Humerus. Clin Shoulder Elb. 2017;20(4):222-9.
18. Dimakopoulos P, Panagopoulos A, Kasimatis G, Syggelos SA, Lambiris E. Anterior traumatic shoulder dislocation associated with displaced greater tuberosity fracture: the necessity of operative treatment. J Orthop Trauma. 2007;21(2):104-12.
19. Ma J-s, Zhao L-y, Liu T, Fu Q, Chen A. A Retrospective Study in the Treatment of a 2-Part Greater Tuberosity Fracture Using the F3 Biomet Plate. International Surgery. 2016;101:465-72.
20. Schöffl V, Popp D, Strecker W. A simple and effective implant for displaced fractures of the greater tuberosity: the “Bamberg” plate. Archives of Orthopaedic and Trauma Surgery. 2011;131(4):509-12.
21. Chen YF, Zhang W, Chen Q, Wei HF, Wang L, Zhang CQ. AO X-shaped midfoot locking plate to treat displaced isolated greater tuberosity fractures. Orthopedics. 2013;36(8):e995-9.
22. Hu C, Zhou K, Pan F, Zhai Q, Wen W, He X. Application of pre-contoured anatomic locking plate for treatment of humerus split type greater tuberosity fractures: A prospective review of 68 cases with an average follow-up of 2.5 years. Injury. 2018;49(6):1108-12.
23. Jang SH, Song HE, Choi SH. Arthroscopic percutaneous inverted mattress suture fixation of isolated greater tuberosity fracture of humerus. J Orthop Surg (Hong Kong). 2018;26(1):2309499017754108.
24. Bhatia DN, van Rooyen KS, du Toit DF, de Beer JF. Surgical treatment of comminuted, displaced fractures of the greater tuberosity of the proximal humerus: a new technique of double-row suture-anchor fixation and long-term results. Injury. 2006;37(10):946-52.
25. Ji J-H, Jeong J-J, Kim Y-Y, Lee S-W, Kim D-Y, Park S-E. Clinical and radiologic outcomes of arthroscopic suture bridge repair for the greater tuberosity fractures of the proximal humerus. Archives of Orthopaedic and Trauma Surgery. 2017;137(1):9-17.
26. Park SE, Jeong JJ, Panchal K, Lee JY, Min HK, Ji JH. Arthroscopic-assisted plate fixation for displaced large-sized comminuted greater tuberosity fractures of proximal humerus: a novel surgical technique. Knee Surg Sports Traumatol Arthrosc. 2016;24(12):3892-8.
27. Bogdan Y, Gausden EB, Zbeda R, Helfet DL, Lorich DG, Wellman DS. An alternative technique for greater tuberosity fractures: use of the mesh plate. Arch Orthop Trauma Surg. 2017;137(8):1067-70.
28. Elkady RH, Fuda N. Percutaneous screw fixation of isolated fractures of the greater tuberosity of the humerus. International Journal of Orthopaedics Sciences. 2017;3:256-60.
29. Li R, Cai M, Tao K. Arthroscopic reduction and fixation for displaced greater tuberosity fractures using the modified suture-bridge technique. International Orthopaedics. 2017;41(6):1257-63.
30. Dussing F, Plachel F, Grossauer T, Hoffelner T, Schulz E, von Keudell A, et al. Anterior shoulder dislocation and concomitant fracture of the greater tuberosity: Clinical and radiological results. Obere Extrem. 2018;13(3):211-7.
31. Cheng MF, Hung SH, Su YP, Chiang CC, Chang MC, Chiu FY. Displaced isolated greater tuberosity fractures of elder adults treated with plate osteosynthesis. J Chin Med Assoc. 2019;82(4):318-21.
32. Plachel F, Schanda JE, Ortmaier R, Auffarth A, Resch H, Bogner R. The “triple dislocation fracture”: anterior shoulder dislocation with concomitant fracture of the glenoid rim, greater tuberosity and coracoid process—a series of six cases. Journal of Shoulder and Elbow Surgery. 2017;26(9):e278-e85.
33. Xue G, Chahal K, Lim T, Hu S, Li S, Liu J. Titanium mini locking plate with trans-osseous sutures for the treatment of humeral greater tuberosity fracture osteosynthesis versus PHILOS: a retrospective view. Int Orthop. 2018;42(10):2467-73.
34. Liao W, Zhang H, Li Z, Li J. Is Arthroscopic Technique Superior to Open Reduction Internal Fixation in the Treatment of Isolated Displaced Greater Tuberosity Fractures? Clinical Orthopaedics and Related Research®. 2016;474(5).
35. Wang YP, Zhao JZ, Huangfu XQ, Liu WX, Jiang Y, Zhou XH, et al. Arthroscopic reduction and fixation for isolated greater tuberosity fractures. Chin Med J (Engl). 2012;125(7):1272-5.
36. Zhang Q, Xiang M, Li YP, Yang JS. Arthroscopic Management of Glenoid and Greater Tuberosity Bipolar Fractures. Orthop Surg. 2020;12(5):1405-12.
37. Yoon TH, Choi CH, Choi YR, Oh JT, Chun YM. Clinical outcomes of minimally invasive open reduction and internal fixation by screw and washer for displaced greater tuberosity fracture of the humerus. J Shoulder Elbow Surg. 2018;27(6):e173-e7.

38. Cho NS, Moon SC, Rhee YG. Clinical Results of Various Surgical Techniques for Isolated Fracture of Greater Tuberosity of Humerus. J Korean Fract Soc. 2013;26(2):133-9.
39. Corbacho B, Duarte A, Keding A, Handoll H, Chuang LH, Torgerson D, et al. Cost effectiveness of surgical versus non-surgical treatment of adults with displaced fractures of the proximal humerus: economic evaluation alongside the PROFHER trial. Bone Joint J. 2016;98-b(2):152-9.
40. Sabharwal S, Carter AW, Rashid A, Darzi A, Reilly P, Gupte CM. Cost analysis of the surgical treatment of fractures of the proximal humerus: an evaluation of the determinants of cost and comparison of the institutional cost of treatment with the national tariff. Bone Joint J. 2016;98-b(2):249-59.