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RESEARCH

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Comparison of the clinical outcomes and radiological parameters between the greater tuberosity strengthened proximal humeral plate and the proximal humeral internal locking system plate in the minimally invasive plate osteosynthesis treatment of proximal humeral fractures involving the greater tuberosity: a retrospective cohort study

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Abstract

Background With the gradual promotion of minimally invasive plate osteosynthesis (MIPO) in the treatment of proximal humeral fractures, some patients using the proximal humeral internal locking system (PHILOS) plate experience significant displacement of the fixed greater tuberosity. However, this is rarely seen in patients using a new plate named the greater tuberosity strengthened proximal humeral plate (GTSPHP). Notably, a comparison of these two plates is lacking. Therefore, we aimed to retrospectively compare the clinical outcomes and radiological parameters of MIPO using the GTSPHP and PHILOS plates.

Methods The data of 40 patients with proximal humeral fractures involving the greater tuberosity who underwent MIPO performed by the same physician between 1 April 2019 and 31 December 2022 were retrospectively analysed. Sixteen and 24 patients were included in the GTSPHP and PHILOS plate groups, respectively and followed up for at least 1 year postoperatively. General clinical characteristics, perioperative data, postoperative follow-up clinical outcomes, complications, and reduction loss of the greater tuberosity were compared between the two groups.

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Results No significant differences were found in age, sex, affected side, injury mechanism, fracture type, injury to surgery time, operative time, postoperative hospital stay, the shortened version of the Disabilities of the Arm, Shoulder, and Hand questionnaire (QuickDASH) score, and Constant score between the two groups. However, the GTSPHP group was superior to the PHILOS plate group regarding surgical incision length, intraoperative blood loss, and the 11-point numerical rating scale score on the first, second and third postoperative days. In the PHILOS plate group, three patients had fracture malunion; both groups showed no signs of incision infection, fracture non-union, screw cut-out, or subacromial impingement syndrome. Both groups showed no significant differences in complication rates. The risk of reduction loss of greater tuberosity was lower in the GTSPHP group than in the PHILOS plate group.

Conclusions Our study showed that in MIPO treatment of proximal humeral fractures involving the greater tuberosity, the GTSPHP outperformed the PHILOS plate in terms of intraoperative blood loss, surgical incision length, short-term postoperative pain, and fixation capability of the greater tuberosity. However, further research is needed to confirm these findings.

Clinical trial number Not applicable.

Keywords Poximal humeral fractures, Greater tuberosity, Minimally invasive plate osteosynthesis, Proximal humeral internal locking system, Shoulder function

Background

Proximal humeral fractures are a common type of fracture, accounting for approximately 5–6% of adult fractures [1, 2]. At present, the treatment of proximal humeral fractures is categorised into conservative and surgical treatments, selected based on various factors, including patient characteristics (age, sex, comorbidities, and expected prognosis), injury conditions (type of fracture and degree of displacement), and the attending physician's clinical experience [3]. Unstable or significantly displaced proximal humeral fractures usually necessitate surgical treatments, including intramedullary device fixation, minimally invasive plate osteosynthesis (MIPO), open reduction internal fixation (ORIF), and shoulder arthroplasty. Of these, the ORIF is the primary surgical option. A meta-analysis found that MIPO was superior to ORIF in terms of operative time, blood loss, postoperative pain, fracture union time, and functional outcomes [4]. Therefore, MIPO has recently become increasingly popular owing to its minimally invasive aesthetics and rapid recovery.

Our team have used the MIPO technique for the treatment of proximal humeral fractures for many years. During the follow-up of patients with associated greater tuberosity fractures, we observed that some patients treated with the proximal humeral internal locking system (PHILOS) plate experienced significant displacement of the greater tuberosity after fixation, whereas this issue was rarely observed in patients treated with a new type of plate. This new plate, which can strengthen the fixation of the greater tuberosity, is named the greater tuberosity strengthened proximal humeral plate (GTSPHP) in our study. However, our literature search revealed that there was no comparative study on the differences between these two methods. Therefore, the present study aimed to investigate the advantages and disadvantages of the two minimally invasive plate treatment options by comparing the general clinical characteristics, perioperative data, postoperative follow-up clinical outcomes, complications, and reduction loss of the greater tuberosity among patients undergoing the two MIPO treatments.

Methods

Patient selection

This retrospective study was conducted at a Level 1 trauma centre and approved by the Ethics Committee of our hospital (approval No. 2024–K–101–01). Data stored in the electronic medical records system were retrospectively analysed. Between 1 April 2019 and 31 December 2022, 78 patients with proximal humeral fractures involving the greater tuberosity were treated using MIPO performed by the same physician. This physician had been performing MIPO for proximal humeral fractures since 2016 and had completed dozens of cases before this study. Forty patients were enrolled in this study after applying the exclusion criteria and they were categorised into the GTSPHP ($n = 16$) and PHILOS plate groups ($n = 24$). The patients were followed up for at least 1 year after surgery. A schematic flow diagram illustrating the inclusion and exclusion process is shown in Fig. 1.

The inclusion criteria were as follows: (1) surgery between 1 April 2019 and 31 December 2022; (2) met the diagnostic criteria for proximal humeral fractures involving the greater tuberosity; (3) MIPO treatment; (4) surgeries were performed by the same primary surgeon; (5) aged ≥ 18 years at the time of injury. The exclusion criteria were as follows: (1) preoperative main neurovascular injury; (2) injury elsewhere that may affect shoulder function; (3) other surgeries during the operation; (4) a history of ipsilateral shoulder disease; (5) a serious chronic

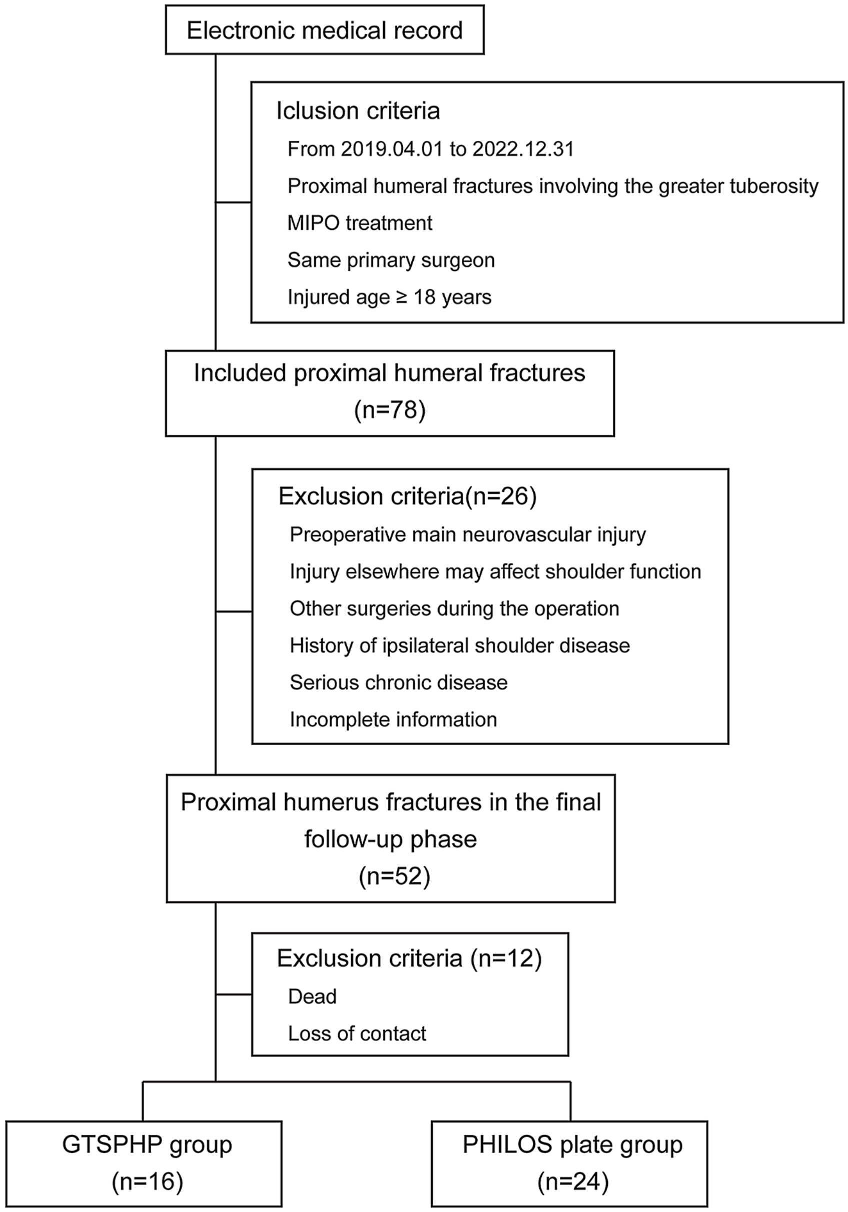

Fig. 1 Schematic flow diagram illustrating the process of patient selection for this study

disease; (6) lack of complete information required for this study; (7) death of patients; and (8) loss of contact with patients.

Surgical procedure

In the GTSPHP group, after successful general or brachial plexus anaesthesia, the beach position was maintained, and the affected side was routinely disinfected and taped to the surgical field. Starting from the anterior border of the acromion on the affected side, an incision of approximately 4–5 cm in length was made, making an angle of 30° forward to the line connecting the anterior border of the acromion and the lateral condyle of the humerus. The skin incision was followed by a blunt dissection of the subcutaneous tissue, separating the deltoid muscle between the anterior and middle fascicle gaps to expose the proximal humeral fracture on the affected side; subsequently, 1 – 0 Ethibond suture (Ethicon, Somerville, NJ) was used to fixate the greater tuberosity. The fracture end was reset, and a Kirschner pin was used for temporary fixation. An appropriate GTSPHP (WEGO, Shandong, China) was selected, the plate percutaneous aiming frame was assembled, and the plate was inserted into the distal end along the periosteum after completing the assembly. The plate was located at the distal end of the greater tuberosity 4–8 mm and the posterior aspect of the interosseous groove of the biceps brachii muscle 4–8 mm, and Kirschner pins were punched in for temporary fixation.

At the distal end, a Kirschner pin was inserted through the targeting sleeve to centrally fix the distal end of the plate; a common hole was then drilled through another targeting sleeve and a common screw was screwed in. The first row of proximal locking screws was drilled and screwed in, and the height of the plate position and fracture reduction were confirmed by intraoperative C-arm radiographic examination. If satisfactory, the proximal end of the plate was fixed with several locking screws, the locking holes were drilled through the aiming socket at the distal end, and two locking screws were screwed in. The aiming bracket was removed after checking using a C-arm radiography machine. Subsequently, a solid bendable sleeve was inserted into the locking screw hole on the plate corresponding to the position of the greater tuberosity. Thereafter, it was bent to fit the greater tuberosity and switched to a hollow locking sleeve to drill a hole and insert one locking screw. The greater tuberosity suture was knotted and fixed, followed by saline irrigation, suture repair of the ruptured rotator cuff, layer-by-layer closure of the wound to the skin, and dressing application. The surgical diagrams are shown in Fig. 2a-f.

In the PHILOS plate group, after successful general anaesthesia or brachial plexus anaesthesia, the beach position was taken, and the affected side was routinely disinfected and taped to the surgical field. Starting from the anterior border of the acromion on the affected side, an incision of approximately 4–5 cm in length was made, making an angle of 30° forward to the line connecting the anterior border of the acromion and the lateral condyle of the humerus. The skin incision was followed by blunt dissection of the subcutaneous tissue, separating the deltoid muscle between the anterior and middle fascicle gaps to expose the proximal humeral fracture on the affected side; a 1 – 0 Ethibond suture (Ethicon, Somerville, NJ) was used to fixate the greater tuberosity. The fracture end was reset, and a Kirschner pin was used for temporary fixation. An appropriate PHILOS plate (DePuy Synthes, Zuchwil, Switzerland, or CANWELL, Zhejiang, China, or WEGO, Shandong, China) was selected, using the plate as a reference, and the distal incision was made in approximately the distal approximately 2–4 cm portion of the conventional deltopectoral approach. Blunt dissection was used to expose the underlying tissue, followed by periosteal stripping to create a subperiosteal tunnel by subdividing the periosteum. The suture was passed through the plate, the bone was implanted in the fracture end, and a locking plate was inserted along the subperiosteal tunnel. The plate was located 4–8 mm distal to the greater tuberosity and 4–8 mm posterior to the interosseous groove of the biceps brachii muscle; a Kirschner pin was used for temporary fixation. Afterwards, a common hole was drilled in the distal end of the plate and secured with a screw. The proximal end of the plate was punched to accommodate the first row of the locking screws, which was examined using intraoperative C-arm radiography to confirm the positional height of the plate and fracture reduction. If satisfactory, the plate was fixed with several locking screws. The greater tuberosity suture was knotted and fixed, followed by saline irrigation, suture repair of the ruptured rotator cuff, layer-by-layer closure of the wound to the skin, and dressing application. The surgical diagrams are shown in Fig. 2g-j.

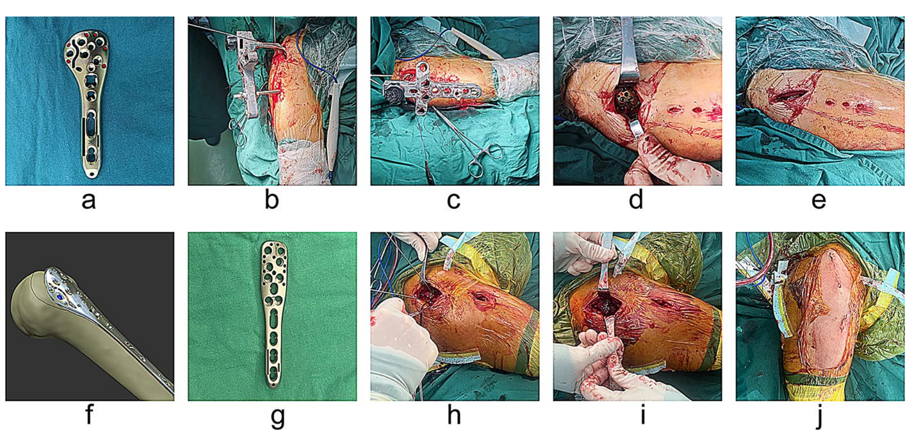

Fig. 2 Surgical diagrams: GTSPHP group (**a**-**f**) and PHILOS plate group (**g**-**j**). a. This is an image of GTSPHP. The holes marked with red circles on the plate can be used to pass sutures for fixing the greater and lesser tuberosities; **b** and **c**. Screwing in the distal screws using an aiming frame; **d**. Confirming the plate position on the proximal humerus; **e**. Final incision length; **f**. A simplified three-dimensional representation, created using Cinema 4D 2023 (Maxon, Friedrichsdorf, Germany), demonstrates the fixation effect of GTSPHP on the greater tuberosity. In the representation, the humerus is shown in yellow, the GTSPHP in silver, and the locking screw in blue. The black line on the humerus indicates the fracture line of the greater tuberosity. Note that this representation is for illustrative purposes only and is not to scale. **g**. PHILOS plate; **h**. Knotting and fixing the greater tuberosity suture; i. Confirming the plate position on the proximal humerus; **j**. Final incision length

Postoperative care

The wound dressing was changed every 3–5 days for 2 weeks after surgery. Postoperative antibiotics were administered for 48–72 h. The shoulder was immobilised with a neck and shoulder strap for 3 weeks after surgery. Passive movement below the shoulder was allowed for 3 weeks after surgery to prevent postoperative shoulder adhesions and upper limb swelling, and improve shoulder joint function. Passive movement above the shoulder and active movement below the shoulder were allowed 3–6 weeks after surgery. At 6 weeks postoperatively, active and passive movements were allowed over the full shoulder range.

General clinical characteristics and perioperative data

The patients' hospitalisation records and imaging data were reviewed. General clinical characteristics included age, sex, affected side, injury mechanism, fracture type, and injury to surgery time. Fractures were classified by two orthopaedic surgeons using radiography and computed tomography (CT) according to the AO/OTA [5] and Neer classifications [6]. Perioperative data included operative time, intraoperative blood loss, surgical incision length, short-term postoperative pain, and length of postoperative hospital stay. An 11-point numerical rating scale (NRS) score [7–9] was used to assess short-term postoperative pain.

Outcome evaluation

The following two scores were used to assess shoulder functional outcomes and recorded at the final follow-up. First, the shortened version of the Disabilities of the Arm, Shoulder, and Hand questionnaire (QuickDASH) was used to assess the physical functions and symptoms associated with musculoskeletal disorders of the upper extremities [10–12]. Second, the Constant score was used to assess shoulder pain, activities of daily living, range of motion, and strength [13–15]. The pain score of the Constant score evaluates long-term postoperative pain.

The patients were monitored for the following complications: incision infection, fracture malunion, fracture non-union, screw cut-out, and shoulder impingement syndrome.

Imaging data were measured using digital callipers in a picture archiving and communication system. The reduction loss of the greater tuberosity was recorded; this was defined as the maximum displacement distance of the greater tuberosity compared between the radiographic images obtained within 3 days postoperatively and the images obtained 1 month postoperatively. The reduction loss of the greater tuberosity was divided into three grades: < 2 mm, ≥ 2 mm and < 5 mm, and ≥ 5 mm.

Statistical analysis

All statistical analyses were performed using SPSS for Windows version 26 (IBM Corp., USA) and Prism 9 software (GraphPad Software, La Jolla, CA, USA), and statistical significance was set at $P < 0.05$. Means ± standard deviation were used to describe the quantitative data, and frequencies (%) were used to describe the categorical data. The Kolmogorov–Smirnov test was used to check for normal distribution of the data, and the Levene's test was used to check for homogeneity of variances between two groups of data. Two independent sample t-tests were used when the data were normally distributed. The Mann–Whitney U test was used if the data were skewed. The chi-squared test or Fisher's precision probability test was used to check for differences between categorical data.

Results

Forty patients (eight men and 32 women) were enrolled in this study. The average age of patients was 57.50 ± 14.01 years (range: 21–80 years). The patients were followed up for at least 1 year after surgical intervention, with a follow-up duration of 26.88 ± 12.26 months (range: 12–51 months). A typical case in the GTSPHP group is shown in Fig. 3, and a typical case in the PHILOS plate group is shown in Fig. 4.

Table 1 summarises the general clinical characteristics of the patients in the GTSPHP and PHILOS plate groups. No significant differences were found between the two groups in terms of age, sex, affected side, injury mechanism, fracture type (AO/OTA and Neer classifications), and injury to surgery time.

Table 2 and Fig. 5 summarize the perioperative data of the patients in the GTSPHP and PHILOS plate groups. Intraoperative blood loss was lower in the GTSPHP group than in the PHILOS plate group ($P = 0.018$). Surgical incision length was shorter in the GTSPHP group than that in the PHILOS plate group ($P < 0.001$), and the 11-point NRS scores on the first, second and third postoperative days were lower in the GTSPHP group than that in the PHILOS plate group (1st day: $P = 0.036$; 2nd day: $P = 0.044$; 3rd day: $P = 0.008$). However, there were no statistically significant differences between the two groups in terms of operative time and length of postoperative hospital stay.

Table 3 summarises the functional outcomes of the patients in the GTSPHP and PHILOS plate groups. No statistically significant differences were found between the two groups in the QuickDASH and Constant scores; in addition, there were no statistically significant differences in pain, activities of daily living, range of motion, and strength scores in the Constant score between the two groups.

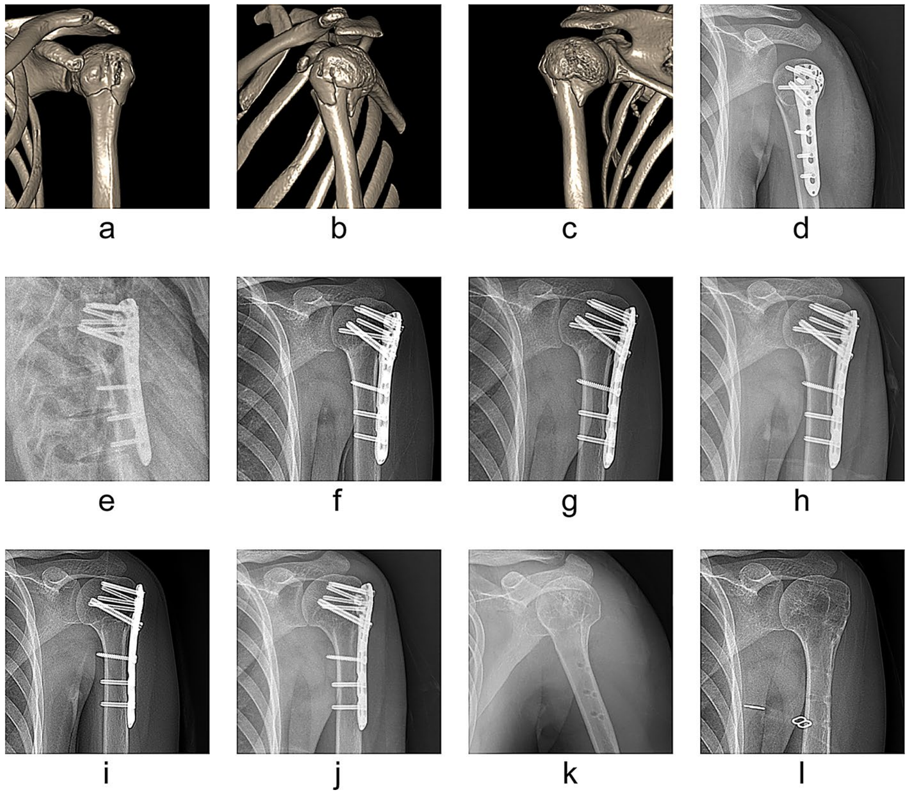

Fig. 3 A young female, accidentally fall incident, left proximal humerus fractures, type B (AO/OTA classification), 2-part (Neer classification). **a**, **b** and **c**. Preoperative three-dimensional computed tomography reconstruction images; **d** and **e**. The postoperative X-ray images on the day of surgery show satisfactory reduction and fixation; **f**. The X-ray image taken 1 month postoperatively shows that the fracture remains stable with no displacement after fixation; **g**. The X-ray image taken 2 months postoperatively; **h**. The X-ray image taken 3 months postoperatively shows that the fracture has achieved union; **i**. The X-ray image taken 6 months postoperatively shows good fracture union. **j**. The X-ray image taken 14 months postoperatively shows good fracture union; **k**. The X-ray image taken the day after the implant removal surgery shows good fracture union and complete removal of the implant; **l**. The X-ray image taken 1 month after the implant removal surgery show good fracture union

Of the 40 included patients, 20 (50.0%) underwent internal implant removal after fracture healing, with no statistically significant difference between the two groups ($P = 1.000$). In the PHILOS plate group, three (12.5%) patients experienced fracture malunion, whereas there were none in the GTSPHP group. There were no cases of incision infection, fracture non-union, screw cut-out, or subacromial impingement syndrome in both groups. The incidence rates of complications between the two groups were not statistically significant ($P = 0.391$).

Figure 6 summarises the reduction loss of the greater tuberosity in the GTSPHP and PHILOS plate groups. The results showed that one (6.3%) and 10 (41.7%) patients had a reduction loss of the greater tuberosity in the GTSPHP and PHILOS plate groups, respectively; thus, the GTSPHP group was superior to the PHILOS plate group in terms of the reduction loss of the greater tuberosity (1/16 vs. 10/24, $P = 0.036$). The patient in the GTSPHP group was classified as having a Neer 3-part fracture; in the PHILOS plate group, one patient was classified as having a Neer 2-part fracture, seven as having a Neer 3-part fracture, and two as having a Neer 4-part fracture. Based on the Neer classification, there was no statistically significant difference in the number of patients who experienced reduction loss ($P = 0.149$). In the GTSPHP group, one (6.3%) patient had a reduction loss < 2 mm, whereas in the PHILOS plate group, six (25.0%) patients had a reduction loss < 2 mm, three (12.5%) patients had had a reduction loss ≥ 2 mm and < 5 mm, and one (4.2%) patient had a reduction loss ≥ 5 mm. The follow-up of the case with ≥ 5 mm reduction loss is shown in Fig. 7.

Discussion

To the best of our knowledge, this is the first study to compare the minimally invasive treatment of proximal humeral fractures involving the greater tuberosity using the GTSPHP and PHILOS plate. Our study demonstrated that the GTSPHP group had a significant advantage over the PHILOS plate group in terms of intraoperative blood loss, surgical incision length, short-term postoperative pain, and greater tuberosity fixation; however, there were no statistically significant differences between both groups in terms of postoperative functional scores

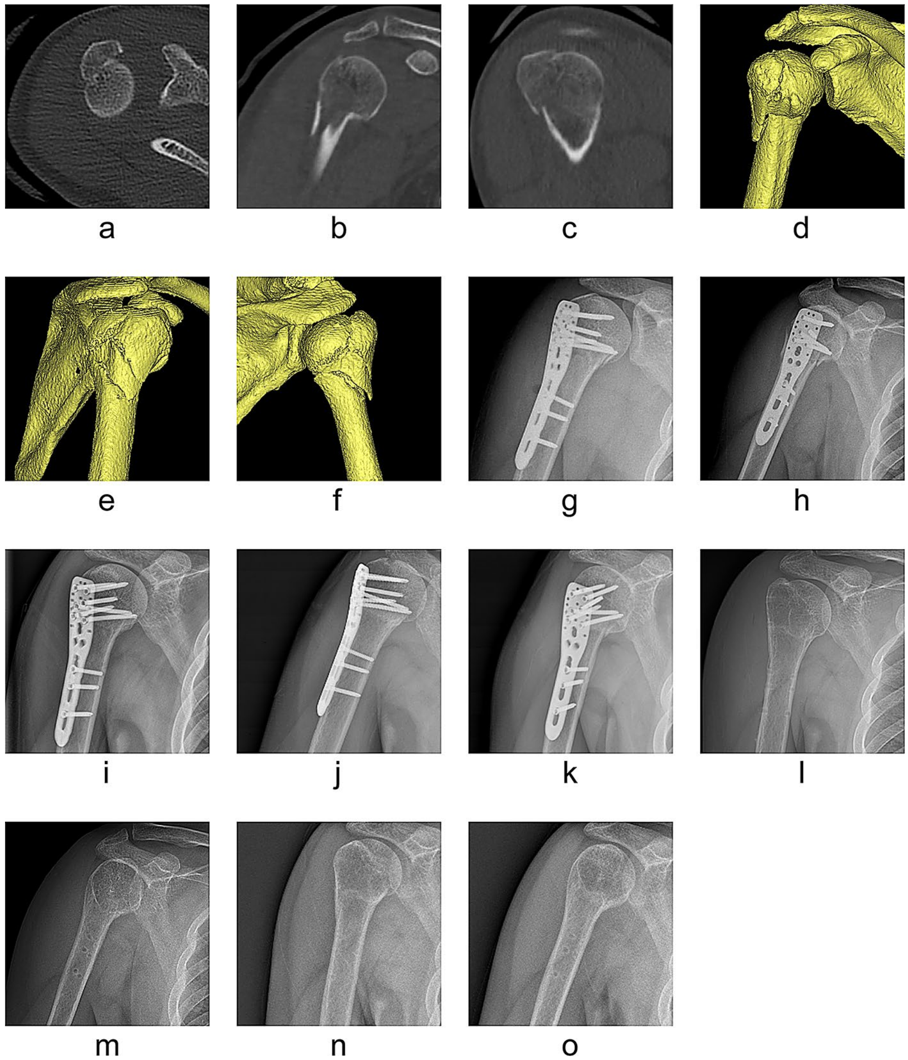

Fig. 4 A middle-aged man, accidentally fall incident, right proximal humerus fractures, type B (AO/OTA classification), 2-part (Neer classification). **a**, **b** and **c**. Preoperative two-dimensional computed tomography images; **d**, **e** and **f**. Preoperative three-dimensional reconstruction computed tomography images were generated by importing two-dimensional computed tomography images into Mimics 21.0 (Materialise, Leuven, Belgium). **g** and **h**. The postoperative X-ray images on the first day show satisfactory reduction and fixation; **i**. The X-ray image taken 1 month postoperatively shows that the fracture remains stable with no displacement after fixation; **j** and **k**. The X-ray images taken 3 months postoperatively show that the fracture has achieved union; **l** and **m**. The X-ray images taken 13 months after the fracture surgery, which were 3 days after the implant removal surgery, show good fracture union and complete removal of the implant; **n** and **o**. The X-ray images taken 14 months after the fracture surgery, which were 1 month after the implant removal surgery, show good fracture union

and complications. This suggests that the GTSPHP has a lower surgical risk and that the less severe postoperative pain associated with the GTSPHP facilitates the early return of patients to functional exercise. Additionally, the GTSPHP has a stronger ability to fix the greater tuberosity.

Although there is no consensus among orthopaedic surgeons on the optimal treatment for proximal humeral fractures [16, 17], surgical intervention is generally required for unstable or significantly displaced proximal humeral fractures in clinical practice. ORIF is the traditional approach for proximal humeral fractures via the deltopectoral muscle. The deltopectoral approach provides a broad surgical field of view. Some study indicates that for Neer 4-part proximal humerus fractures, the deltopectoral approach is more effective in achieving anatomical reduction and restoring the range of motion in the shoulder joint compared to the deltoid-split approach [18]. However, a long incision and extensive soft tissue dissection in the deltopectoral approach can affect the blood supply to the fracture fragments, thereby increasing the incidence of avascular necrosis of the humeral head [15, 19]. Moreover, postoperative pain associated with excessive trauma is not conducive to early rehabilitation of the shoulder joint. MIPO is a minimally invasive deltoid-split approach used to treat

Table 1 Comparison of the general clinical characteristics of the two groups

Variables	GTSPHP group ($n=16$)	PHILOS plate group ($n=24$)	P-value
	Mean ± standard deviation; Frequency (%)		
Age (year)	59.31 ± 16.65	56.29 ± 12.17	0.194
Sex			0.170
Male	1 (6.3)	7 (29.2)	
Female	15 (93.8)	17 (70.8)	
Injuerd side			0.897
Left	9 (56.3)	13 (54.2)	
Right	7 (43.8)	11 (45.8)	
Injury mechanism			0.220
Fall accident	11 (68.8)	18 (75.0)	
Traffic accident	5 (31.3)	3 (12.5)	
Other causes	0 (0.0)	3 (12.5)	
AO/OTA classification			0.876
Type A	3 (18.8)	3 (12.5)	
Type B	11 (68.8)	18 (75.0)	
Type C	2 (12.5)	3 (12.5)	
Neer classification			0.900
2-part	5 (31.3)	8 (33.3)	
3-part	10 (62.5)	13 (54.2)	
4-part	1 (6.3)	3 (12.5)	
Injury to surgery time (d)	3.25 ± 2.54	3.25 ± 2.05	0.712

Table 2 Comparison of the perioperative data of the two groups

Variables	GTSPHP group ($n=16$)	PHILOS plate group ($n=24$)	P-value
	Mean ± standard deviation		
Operative time (min)	70.31 ± 34.18	68.96 ± 17.69	0.434
Intraoperative blood loss (mL)	48.13 ± 17.97	75.00 ± 30.93	0.018*
Incision length (cm)	5.72 ± 0.75	7.21 ± 1.14	< 0.001*
Length of postoperative hospital stay (d)	5.81 ± 1.68	6.17 ± 2.04	0.524

*:$P < 0.05$

Table 3 Comparison of the functional outcome of the two groups

Variables	GTSPHP group ($n=16$)	PHILOS plate group ($n=24$)	P-value
	Mean ± standard deviation; Frequency (%)		
QuickDASH score (point)	12.50 ± 6.83	10.00 ± 5.90	0.134
Constant score[a] (point)	82.94 ± 9.24	86.75 ± 7.79	0.121
Pain	12.50 ± 2.58	13.13 ± 2.47	0.439
Activities of daily living	18.63 ± 3.63	17.79 ± 1.84	0.917
Range of motion	32.75 ± 4.12	33.17 ± 4.49	0.675
Strength	20.94 ± 4.17	21.88 ± 3.23	0.528

[a]: Constant score is composed of four subscales: pain, activities of daily living, range of motion, and strength

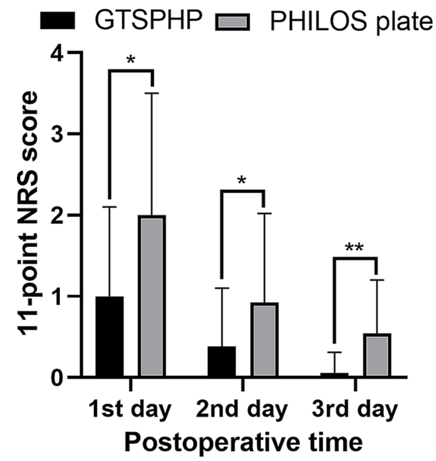

Fig. 5 Comparison of the the 11-point NRS scores on the first, second and third postoperative days in the GTSPHP and PHILOS plate groups. The 11-point NRS scores on the first, second and third postoperative days were lower in the GTSPHP group than that in the PHILOS plate group (1st day: 1.00 ± 1.10 vs. 2.00 ± 1.50, $P=0.036$; 2nd day: 0.38 ± 0.72 vs. 0.92 ± 1.10, $P=0.044$; 3rd day: 0.06 ± 0.25 vs. 0.54 ± 0.66, $P=0.008$). *: $P<0.05$; **: $P<0.01$

proximal humeral fractures. The deltoid-split approach features a short incision and avoids the need for extensive soft tissue dissection, thereby reducing the risk of damage to blood supply to the humeral head [15, 20, 21]. Xie et al. [22] concluded that the deltoid-split approach causes less soft tissue trauma while preserving periosteal circulation, thereby facilitating fracture healing. However, MIPO technology requires a longer learning-curve, and a meta-analysis found that the probability of axillary nerve damage was higher in MIPO than in ORIF [4].

In our study, all included patients were not followed up with axillary nerve injury. It has been shown that splitting the deltoid muscle longitudinally in the direction of the deltoid muscle fibres from the acromion downwards would not normally cause damage to the axillary nerve, provided that the separation length does not exceed 6 cm [18, 23, 24]. Therefore, we believe that axillary nerve injury may be related to the choice of surgical incision and operator's experience. In our insertion of the GTSPHP and PHILOS plate, we made a proximal incision between the anterior deltoid and middle fascicles, using an approach that splits the anterior deltoid and middle fascicles. The incision was made at 30° forward to the line connecting the anterior border of the acromion and humeral lateral condyle. Afterwards, the plate was inserted snugly beneath the periosteal stripping device, aiming to better preserve the vascular nerves and reduce the risk of injury to the anterior humeral circumflex artery and axillary nerve. The distal incision in the PHILOS plate was selected to be approximately a 2–4 cm portion of the distal end of the conventional deltopectoral approach to maximise the preservation of the deltoid muscle insertion points and facilitate the

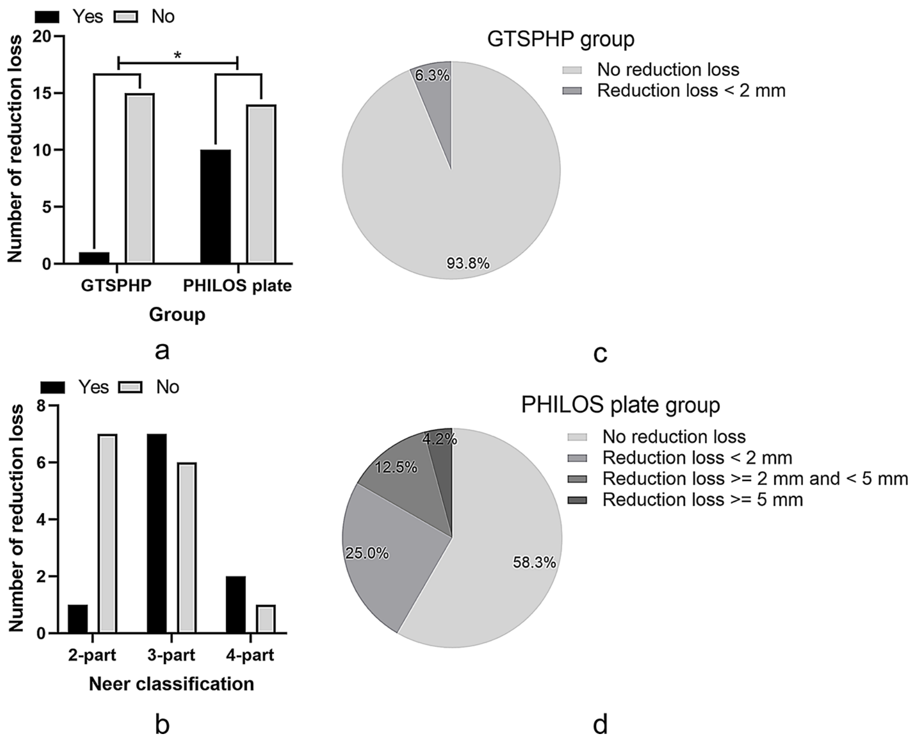

Fig. 6 Comparison of the reduction loss of the greater tuberosity in the GTSPHP and PHILOS plate groups.a. The bar chart shows the number of reduction loss cases in both groups; b. The bar chart shows the number of reduction loss cases in each Neer classification within the PHILOS group; c and d. The pie charts show the proportion of reduction loss cases in both groups. *:$P < 0.05$

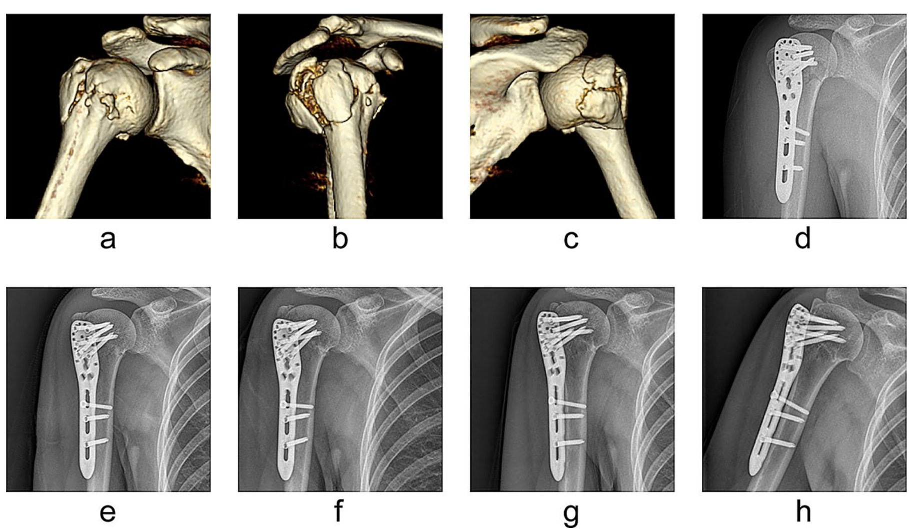

Fig. 7 A middle-aged female, accidentally fall incident, right proximal humerus fractures, type B (AO/OTA classification), 3-part (Neer classification). **a**, **b** and **c**. Preoperative three-dimensional computed tomography reconstruction images; **d**. Postoperative X-ray image on the day of surgery shows satisfactory reduction and fixation; **e**. The X-ray image taken 1 month postoperatively shows that the greater tuberosity has displaced by more than 5 mm compared to image d; **f**. The X-ray image taken 2 months postoperatively shows that the greater tuberosity has further displaced compared to image e; **g**. The X-ray image taken 3 months postoperatively shows that the fracture has achieved union except for the greater tuberosity, which has displaced slightly compared to image f; **h**. The X-ray image taken 11 months postoperatively shows malunion of the greater tuberosity

enlargement of the incision, if necessary. In the GTSPHP group, a targeting frame was used to assist the placement of the three screws distal to the plate, which allows for a smaller surgical incision, resulting in less intraoperative bleeding and postoperative pain; however, this does not compromise the exposure of the field of view of the fracture for restoration. The distal incision of the PHILOS plate was selected to better preserve the vascular nerves and reduce the injury risk to the anterior rotator humeri artery and axillary nerve.

Regarding complications, three cases of malunion were observed in the PHILOS plate group. Among them, two patients experienced internal rotation malunion of the humeral head, which may have been caused by poor reduction owing to limited exposure during MIPO. Despite this, the large range of motion in the shoulder joint indicated that there was no significant impact on the patients' shoulder function. Additionally, one patient experienced malunion of the greater tuberosity, resulting from severe loss of reduction at this site.

The degree of greater tuberosity displacement is one of the most important criteria for evaluating the quality of proximal humeral fracture reduction [25], and excessive reduction loss of the greater tuberosity increases the probability of malunion and subacromial impingement syndrome. We considered a loss of < 2 mm to be an acceptable standard for the reduction and fixation of fractures, a loss of ≥ 2 mm and < 5 mm to require further close follow-up, and a loss of ≥ 5 mm to be considered for revision surgery. In our study, we compared the radiographs within 3 days and 1 month postoperatively. The GTSPHP group had a lower risk of reduction loss of the greater tuberosity than did the PHILOS plate group. This suggests that the greater tuberosity groove and screws in the GTSPHP provide a reinforcing effect on the greater tuberosity. Ten patients with a reduction loss of the greater tuberosity of < 5 mm in both groups did not experience growth of 5 mm or more during subsequent follow-up visits. Regarding the patient in the PHILOS plate group with ≥ 5 mm reduction loss, the decision to continue monitoring was reached, after a discussion with the patient, because the posterior-lateral displacement had a relatively minor impact on shoulder function. From 3 months postoperatively, the greater tuberosity did not show further displacement; therefore, revision surgery was not performed, resulting in a satisfactory functional outcome.

Included patients were treated by the same physician, which to some extent prevented bias because of the surgical approach and experience of the attending surgeon; however, this resulted in a single-centre retrospective study with a relatively small number of included cases. A more rigorous design and large randomised controlled trial is required for further validation of our study results.

Conclusions

Our findings revealed that regarding implant selection for MIPO treatment of proximal humeral fractures involving the greater tuberosity, the advantages of the GTSPHP over the PHILOS plate include less intraoperative blood loss, shorter surgical incision length, less short-term postoperative pain, and a stronger fixation capability for the greater tuberosity. However, there were no significant differences in complications between the GTSPHP and PHILOS plate. Therefore, we consider the GTSPHP to be a promising and safe option for the treatment of proximal humeral fractures involving the greater tuberosity. However, larger prospective studies are needed to further validate these findings.

Abbreviations

MIPO	Minimally invasive plate osteosynthesis
PHILOS	Proximal humeral internal locking system
GTSPHP	Greater tuberosity strengthened proximal humeral plate
QuickDASH	The shortened version of the Disabilities of the Arm, Shoulder, and Hand questionnaire
ORIF	Open reduction internal fixation
CT	Computed tomography
NRS	Numerical rating scale

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Author contributions
All authors participated in the conception and design of this study. Jiadi Le, Jianpeng Lu, Jianxiong Zhang and Zhenghao Wu contributed to data collection and analysis. Jiadi Le writed the first draft of the manuscript. Long Chen revised the manuscript. All authors read and agreed to the final manuscript.

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Data availability
The datasets analyzed during this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics Committee of the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University (approval No. 2024–K–101–01), and the need for informed consent was waived by the ethics committee. All procedures involving human participants in this study were conducted in accordance with the principles of the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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