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Assessment of Screw Length of Proximal Humerus Internal Locking System (PHILOS) Plate for Proximal Humeral Fractures Using Three-Dimensional Computed Tomography Scan

Authors' Contribution:
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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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Background: Screw perforation and varus collapse are common complications of treatment with a PHILOS (proximal humerus internal locking system) plate for proximal humerus fractures, which are associated with improper screw length selection and lack of medial column support. The purposes of this study were: (1) to measure the proper length of periarticular screws of the PHILOS plate in the humeral head, and (2) to determine what factors influence the screw length and implantation of the inferomedial support screw.

Material/Methods: Computed tomography (CT) images of the normal proximal humerus in 134 cases were retrospectively reviewed. The length of periarticular screws was measured using three-dimensional (3D) techniques. Intraobserver and interobserver reliability of measurement were evaluated using intraclass correlation coefficients (ICCs). Sex and body height influences on screw length and implantation of the inferomedial screw were analyzed.

Results: All measurements had excellent agreement (ICC>0.75). The screw length and implantation rate of the inferomedial screw were greater in males than in females. Positive correlations were observed between body height and screw length and implantation of the inferomedial screw (all $P<0.001$).

Conclusions: The screws were longer and the implantation rate was higher for inferomedial screws in males than in females, and were positively correlated with body height. Our data can be used as a reference for surgeons to reduce the number of times screws are changed intraoperatively and to reduce operation duration and minimize use of intraoperative fluoroscopy for proximal humerus fractures treated with the PHILOS plate.

MeSH Keywords: Bone Screws • Image Processing, Computer-Assisted • Imaging, Three-Dimensional • Multidetector Computed Tomography • Shoulder Fractures

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Background

Proximal humerus fractures are the third most common fracture in patients over 65 years old, accounting for 4% to 5% of all fractures [1–3]. They are mainly osteoporotic fractures, with an increasing prevalence [1,3]. Most proximal humerus fractures are minimally displaced or nondisplaced and can be treated nonoperatively. However, the remaining approximately 21% of displaced and unstable fractures require surgery [2], including minimally invasive osteosynthesis, open reduction internal fixation (ORIF), intramedullary nail osteosynthesis, and primary hemiarthroplasty or reverse total arthroplasty.

Although there is no consensus regarding optimal treatment of unstable fractures, ORIF with a PHILOS (proximal humerus internal locking system) plate is increasingly used and has achieved better clinical outcomes [4,5]. However, many postoperative complications remain, including intraarticular screw perforation and varus collapse [4,6–8]. These complications may result from the following factors. First, poor bone quality and thin cortices of the proximal humerus limit the tactile feedback of the drill bit [9], which makes selection of proper screw length difficult [10]. Second, the sphericity of the humeral head and diverging and converging locking screw vector make the exact localization of the screw tip using intraoperative fluoroscopy difficult [9,11], and make it hard to determine if the screws are inserted into the glenohumeral cavity. Lastly, the medial column lacks effective support [12–14]. For these reasons, some surgeons reported that shortening the length of the screws could reduce the risk of screw perforation, but this can increase the risk of implant failure [15–18]. The risk of varus collapse can be decreased by maximizing screw length and implanting the inferomedial support screws [12,13], which, paradoxically, may increase the incidence of screw perforation [12]. Thus, it is necessary to know the proper length of periarticular screws in the humeral head and under what circumstances the inferomedial screws can be inserted. These problems have not been sufficiently evaluated. Therefore, the purposes of this study were: (1) to measure the optimal periarticular screw length of the PHILOS plate in the humeral head, and (2) to determine what factors influence the optimal screw length and implantation of inferomedial support screws.

Material and Methods

Participant population

The research protocol was approved by the Committee of Medical Ethics of the hospital, and written informed consents were obtained. A total of 134 consecutive participants were retrospectively enrolled from October 2010 to April 2015. These participants had not been diagnosed with humeral deformities, shoulder osteoarthritis, humeral fractures, or previous humeral trauma. Computed tomography (CT) images of the normal humerus from all participants were analyzed in the study. The participants consisted of 56 males and 78 females, with a mean age of 49.5±9.8 years (range, 22–77 years).

Radiology technique

A 16-detector spiral CT scanner (GE LightSpeed CT; Waukesha, WI, USA) was used. The thin-slice CT axial images of all participants were input into the computer-aided orthopedics clinical research platform (SuperImage orthopedics edition 1.1, Cybermed Ltd., Shanghai, China) [19,20]. In this system, the three-dimensional (3D) images of the shoulder joint were reconstructed using a shaded surface display (SSD). In 3D SSD images, the component bones can be distinguished using a 3D interactive and automatic segmentation technique. The different types of bones were labeled with distinct colors. Thus, the proximal humerus image was generated after removing the clavicle, scapula, and other unrelated bones (Figure 1).

Simulated implantation of fixation devices

In this study, the PHILOS plate with 5 shaft holes (Synthes, Stratec Medical Ltd., Mezzovico, Switzerland) and 3.5-mm-diameter locking screws was used (Figure 2A). The positions of all 9 periarticular locking screws were numbered (Figure 2B). In the 3D SSD images, using a semi-automatic approach, the plate was positioned 8 mm distal to the superior edge of the greater tuberosity and 4 mm lateral to the bicipital groove in the lateral view (Figure 3A) [12,21]. The locking screws had their designed trajectory (Figure 2B).

For 3D SSD images, the screws were inserted through the plate holes along the designed trajectory (Figure 3B). When the screw was completely inserted into the plate hole, the location of screw cap was defined as point A (Figure 3C). Point B was defined as the intersection of the subchondral bone and screw tip (Figure 3D). The optimal length of the screws was equal to the distance between points A and B (Figure 3C, 3D) [22]. The length of screw No. 7 was obtained from 3D measurements (Figure 3C, 3D). Using the same procedure, the optimal lengths of other screws were measured.

If the inferomedial screw No. 8 or No. 9 is inserted into the head segment that was part of the head above the anatomic neck plane (Figure 4), the screw can provide effective support to the medial column [12,13,15,22]; therefore, it was regarded as the effective screw. According to the number of effective inferomedial screws, patients were divided into an unimplanted group (group 0) and an implanted group (group 1 and group 2). Group 0 (Figure 4A), group 1 (Figure 4B, 4C), and group 2 (Figure 4D) were the groups that had zero, 1, and 2 effective inferomedial screws, respectively.

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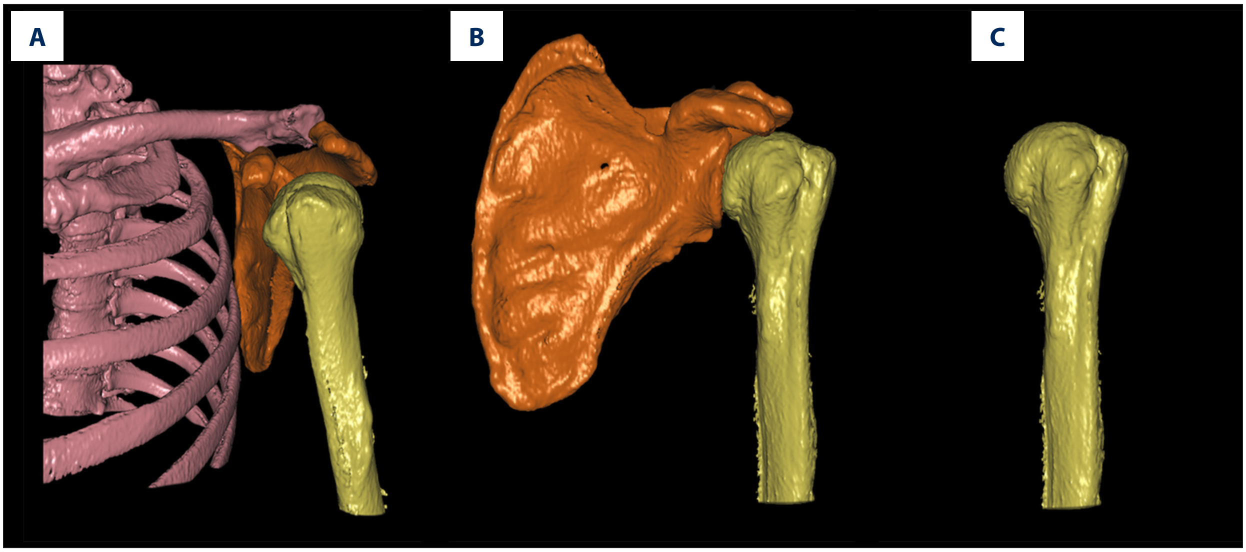

Figure 1. Process of generating the 3D structure of the proximal humerus. (**A**) The images of the humerus, scapula, and other bones were extracted through a 3D interactive and automatic segmentation technique after SSD reconstruction. The different types of bones were labeled with distinct colors. (**B, C**) The humerus and scapula were marked yellow and orange, respectively. The image of the humerus was extracted and those of the other bones were deleted.

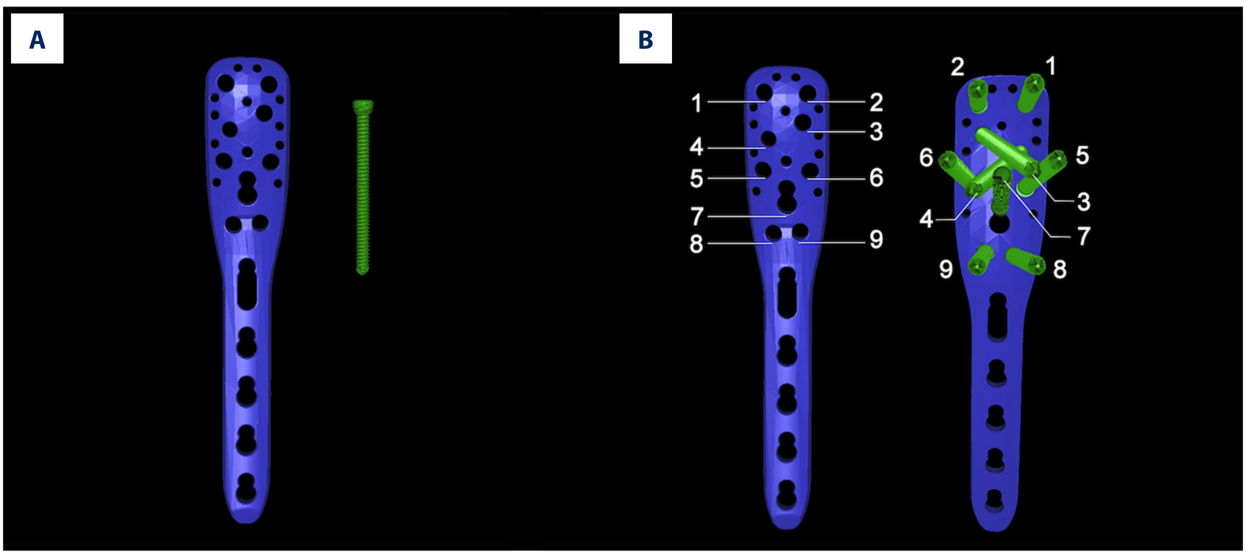

Figure 2. Distribution of the periarticular screws of the PHILOS plate. (**A**) There are 9 screw holes for locking screws in the proximal PHILOS plate (Synthes Inc.), and a 3.5-mm-diameter locking screw is chosen. (**B**) The plate with numbers is shown from the lateral and medial view. Screws No. 8 and No. 9 are the inferomedial support screws.

The measurements of screw length were performed by 3 surgeons (X.J., M.Q., and K.Z.), who were blinded to each other's results. After 5 weeks, the measurements were repeated to evaluate intraobserver reliability by the main examiner (X.J.). The analyses of the relationship among screw length, inferomedial screw, sex, and body height were based on the main examiner's first reading.

Statistical analysis

Statistical analysis was performed using SPSS (version 18.0, Chicago IL, USA). Interobserver and intraobserver reliability was analyzed using intraclass correlation coefficients (ICCs). An ICC less than 0.40 indicated poor agreement, between 0.40 and 0.59 indicated moderate agreement, between 0.60 and 0.74 indicated good agreement, and between 0.75 and 1.00 indicated excellent agreement [23].

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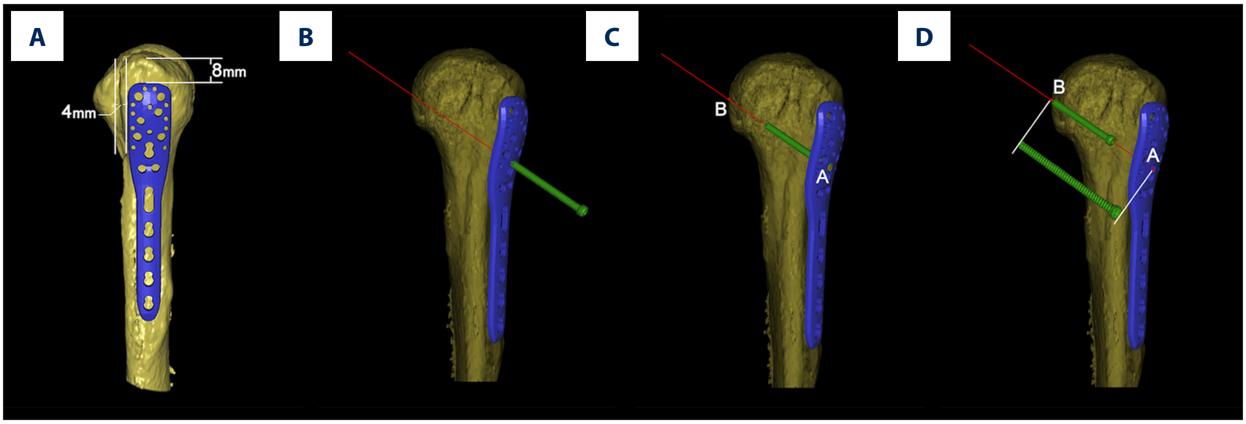

Figure 3. Simulated implantation of the PHILOS plate and screw. (**A**) The plate is positioned 8 mm distal to the superior edge of the greater tuberosity and 4 mm lateral to the bicipital groove. (**B**) The locking screw (No. 7) can be inserted through the plate hole along its designed trajectory (red line). (**C, D**) The optimal screw length is equal to the distance between points A and B. Points A and B are defined as the points on the screw cap and the intersection of the subchondral bone and screw tip, respectively.

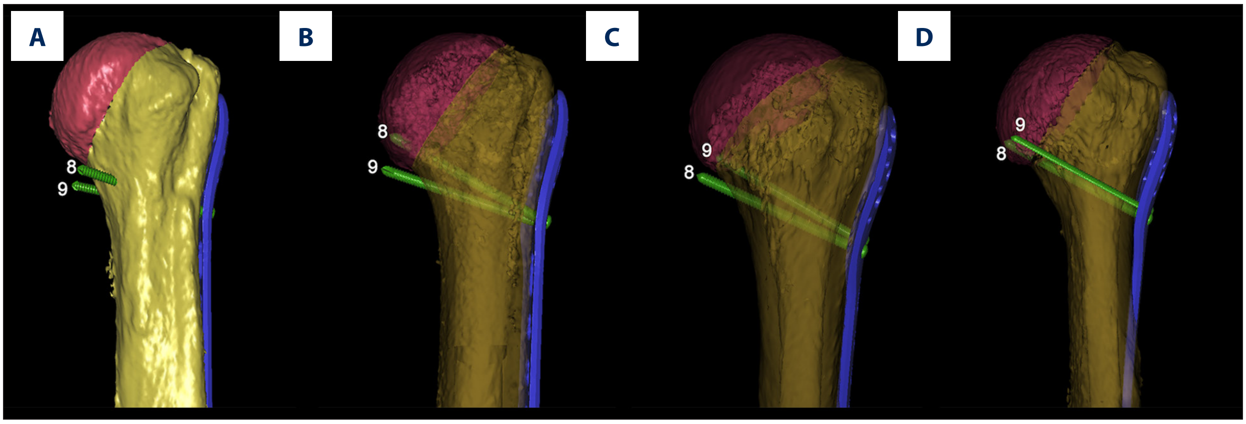

Figure 4. Distribution of the inferomedial support screws. Only the inferomedial screws are inserted into the head segment that is the part of head above the anatomic neck plane (pink part) and are then regarded as the effective screws. (**A**) Both inferomedial screws No. 8 and No. 9 are the ineffective screws. (**B**) Screw No. 8 is the effective screw rather than the other (No. 9). (**C**) Screw No. 9 is the effective screw rather than the other (No. 8). (**D**) Screws No. 8 and No. 9 are the effective screws.

Quantitative data are represented as mean ± standard deviation (SD) and categorical data as absolute frequency. All parameters were examined for normality using the Kolmogorov-Smirnov test. According to the distribution form, the independent sample *t* test or nonparametric Mann-Whitney U test was used for the analysis of binary categorical data. Differences among multiple groups were tested with one-way ANOVA, and if necessary, the least significant difference (LSD) *t* test was also used. Categorical data were analyzed using a chi-square test or a Fisher's exact test. Correlations between body height and screw length were analyzed using simple linear regression. Spearman rank correlation tests were performed to assess associations between body height and the number of effective inferomedial screws. The level of significance was defined as $P<0.05$ for all analyses.

Results

The mean optimal screw lengths are shown in Table 1. The mean lengths of screws No. 1, No. 2, No. 3, No. 4, No. 5, No. 6, No. 7, No. 8, and No. 9 were 42.1 mm (range, 34.5–48.9 mm), 43.9 mm (range, 35.2–52.4 mm), 45.1 mm (range, 35.5–51.6 mm), 45.0 mm (range, 32.9–52.9 mm), 42.8 mm (range, 32.1–50.8 mm), 43.8 mm (range, 36.8–52.3 mm), 47.2 mm (range, 37.2–54.0 mm), 46.6 mm (range, 41.8–50.7 mm), and 47.0 mm (range, 42.1–51.0 mm), respectively. The mean length of all screws was longer in males than in females (all $P<0.001$). There were 70 participants (70/134, 52.2%) in the implanted group, including 38 (35/56, 67.9%) males and 32 (32/78, 41.0%) females. The males had a higher implantation rate of the inferomedial screw ($P=0.002$) (Figure 5A).

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Table 1. The optimal screw length (mean ±SD (mm)).

	Screw position								
	No. 1 (n=134)	No. 2 (n=134)	No. 3 (n=134)	No. 4 (n=134)	No. 5 (n=134)	No. 6 (n=134)	No. 7 (n=134)	No. 8 (n=48)	No. 9 (n=51)
Male	43.6±2.1	46.1±3.4	47.4±2.8	47.2±2.7	45.5±2.3	46.9±2.4	49.7±1.5	47.6±1.8	48.2±1.4
Female	41.0±2.5	42.4±3.2	43.5±2.6	43.4±3.1	40.9±3.2	41.5±2.5	45.4±2.7	45.5±1.6	45.6±1.7
Total	42.1±2.7	43.9±3.8	45.1±3.3	45.0±3.5	42.8±3.6	43.8±3.6	47.2±3.1	46.6±2.0	47.0±2.0
t value	6.554	6.371	8.324	7.405	9.254	12.472	10.771	4.106	6.075
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

n – the number of screws.

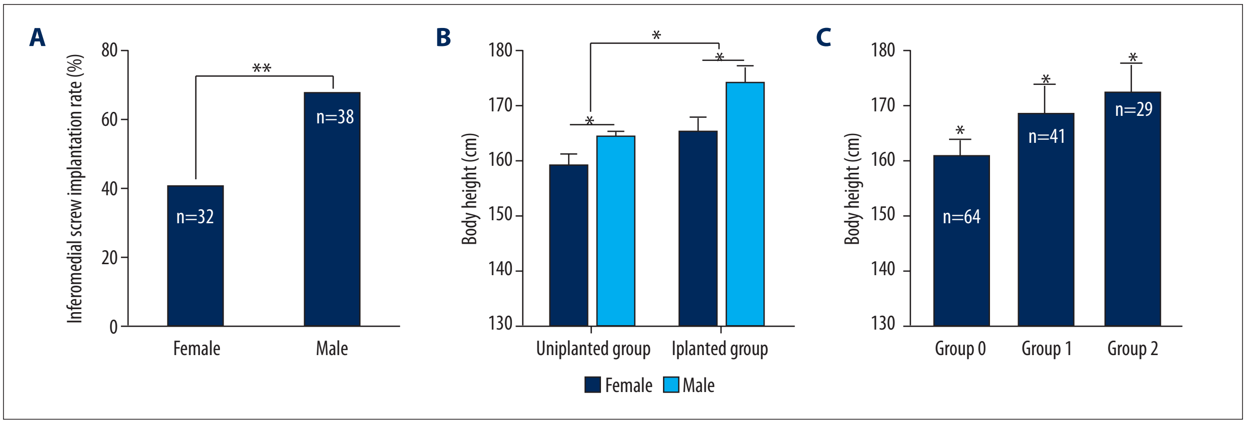

Figure 5. (**A**) Implantation rate of the inferomedial screws in the male group (67.9%) and female group (41.0%) (** *P*=0.002). (**B**) The differences in body height between the unimplanted and implanted groups and males and females (* *P*<0.001). (**C**) The differences in body height among the 3 groups (* *P*<0.001). Group 0, zero inferomedial screw; group 1, 1 inferomedial screw; group 2, 2 inferomedial screws.

Table 2. The correlation of the screw length and body height.

	Screw position								
	No. 1 (n=134)	No. 2 (n=134)	No. 3 (n=134)	No. 4 (n=134)	No. 5 (n=134)	No. 6 (n=134)	No. 7 (n=134)	No. 8 (n=48)	No. 9 (n=51)
r	0.628	0.762	0.795	0.737	0.720	0.826	0.808	0.577	0.649
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

n – the number of screws; r – Pearson's correlation coefficient.

For all participants, the mean body heights were 171.5±5.2 cm (range, 164–181 cm) for the males and 162.0±3.8 cm (range, 155–172 cm) for the females (*P*<0.001). The mean body height was greater (*P*<0.001) in the implanted group (170.5±5.3 cm; range, 161–181 cm) than in the unimplanted group (161±3.1 cm; range, 155–167 cm) (Figure 5B). The correlation between body height and screw length is presented in Table 2, and positive correlations between them were observed (all *P*<0.001). A similar correlation between body height and the number of effective inferomedial screws was found (*r*=0.790, *P*<0.001). Body heights among the 3 groups were significantly different (all *P*<0.001) (Figure 5C).

The ICC values of intraobserver and interobserver reliability of all variables are presented in Figure 6. For the 3D measurement, intraobserver (ICC range, 0.829–0.983) and interobserver (ICC range, 0.810–0.965) ICC values both exceeded 0.75, indicating excellent agreement.

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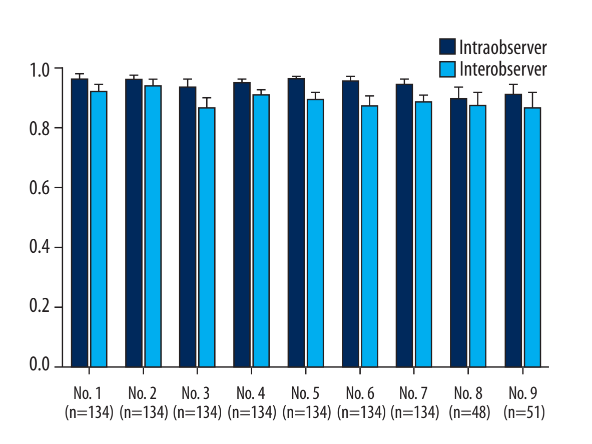

Figure 6. Intraobserver and interobserver reliability of measurement of screw length with the use of 3D CT scans. ICC, intraclass correlation coefficient; n, the number of screws.

Discussion

Locking plates are widely used in the treatment of unstable proximal humerus fractures. Despite having better clinical outcomes, the rate of postoperative complications, including screw perforation and varus collapse, remains high [6–8]. These complications may be reduced with excellent screw purchase and adequate medial column support [6,12], meaning the screws should be implanted for as long as possible and an inferomedial screw should be implanted if possible. However, depending on intraoperative fluoroscopy and surgeon experiences, it was difficult to obtain the proper screw length and examine whether the screws had been inserted into the glenohumeral cavity and whether the inferomedial screw had been implanted effectively [11,24,25]. Based on 3D CT images, we obtained the optimal length of all periarticular screws of the PHILOS plate and found that sex and body height influenced the screw length and implantation of inferomedial screws.

Proper screw length and location are the crucial factors in reducing screw perforation. The rate of perforation was reported to be approximately 8% to 22% [7,26]. A significant age- and sex-related decrease in bone mineral density for women was observed [27,28]. Proximal humerus fractures are mainly osteoporotic fractures [1,3], and poor bone quality is one of the causes of screw penetration [1,9]; it may limit the tactile feedback of the drill bit, which made it difficult to determine the proper screw length. A cadaveric biomechanical study by Liew et al. [22] showed that the screw positioned into the subchondral bone of the medial and inferior region had significantly higher pullout strength. A histomorphometric study by Hepp et al. [29] revealed that the highest bone mineral density and pullout strength were observed in the medial and dorsal aspects of the humeral head. Therefore, the optimal location of the screw was adjacent to the subchondral bone and in the medial-inferior-posterior aspect of the head, preventing screw cutout and varus collapse. The spherical shape of the humeral head and diverging and converging locking screw vectors were also causes of screw perforation [9]. In light of these factors, we could not accurately determine whether the screw had perforated into the glenohumeral joint using traditional intraoperative fluoroscopy alone [24,25]. Spross et al. [25] demonstrated that a combination of multiple projections can reach 100% sensitivity for screw perforation. However, Lowe et al. [24] stated that no combination of projections could reach 100% sensitivity for screw perforation. The detection of screw perforation was likely improved with live and repeated intraoperative fluoroscopy, but this would increase the radiation exposure of surgeons and patients. Even if iatrogenic screw perforation was detected and corrected before leaving the operating room, it may lead to late failure [9]. Thus, the optimal screw length, as determined in this study, could be used as a reference to reduce the risk of screw perforation and reduce the number of times screws need to be changed intraoperatively, as well as reducing operation durations and minimizing use of intraoperative fluoroscopy.

To prevent screw perforation, Ricchetti et al. [16] modified the technique by placing screws away from the subchondral bone. However, 5 of 52 patients in their study had varus collapse, which may be due to poor screw purchase in the head. Placing the plate proximal to the greater tuberosity can increase the use of screws with sufficient length but may lead to subacromial impingement. Therefore, the 2 methods discussed above were not very effective in reducing the rate of screw penetration. Hymes et al. [13] raised a question of whether increasing the total number of screws was a potentially safer method for increasing total screw length. However, increasing the number of screws would increase the loss of bone mass. This problem needs to be clarified in further studies.

In the present study, the examiners obtained excellent intraobserver and interobserver reliability using 3D CT scan in the assessment of the optimal screw length. We found that males had longer screw lengths compared to females. This phenomenon may result from sex differences in body height and others factors. There was a positive correlation between body height and optimal screw length, which may be due to the positive correlation between body height and humeral head size [30]. Therefore, for short women, slightly shorter screws should be used to prevent perforation.

Adequate medial column restoration is crucial in maintaining reduction when locking plates are used in the treatment of proximal humeral fractures. Approximately 16% of the patients had varus collapse [7], which may have resulted from lack of effective medial column support [31]. A cadaveric

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biomechanical study by Hymes et al. [13] found that the medial cortical bone might be the first barrier to failure. Another biomechanical study, by Ponce et al. [32], demonstrated that medial comminution significantly decreased implant stability, and medial column restoration with inferomedial screws can improve the stability of repaired fractures. The biomechanical property could be altered by disrupting the medial periosteal continuity by more than 3 mm [14]. In a clinical study, Gardner et al. [12] showed that the inferomedial screws were most important in maintaining fracture reduction and could improve the stability of fixation, especially for patients with a disrupted medial hinge. Concurrently, the stability of fixation with the implantation of the inferomedial screws can also reduce screw perforation [15]. Therefore, measures in obtaining the stability of fixation should focus on increasing the number and depth of the inferomedial screws [13]. However, the inferomedial screws had the highest risk of intraarticular perforation [24] and were the most difficult screws to accurately evaluate using fluoroscopy [25].

Erhardt et al. [15] showed that a locking plate with inferomedial support screws could reduce screw perforation rate in two-part proximal humeral fractures. However, Katthagen et al. [33] found that inferomedial support screws had no benefit in two-part proximal humeral fractures, which was confirmed by Zhang et al., who stated that no significant advantage of inferomedial screws was observed in two-part proximal humeral fractures compared to three- and four-part fractures [34]. This may suggest that medial column support was less important for fractures with greater intrinsic stability.

In the present study, males had higher implantation rates of inferomedial screws than females, which may be due to sex differences in body height and others factors. We found that greater body height was associated with a greater the number of effective inferomedial screws. This result may be related to the positive correlation between body height and humeral head size [30]. However, there was a significant difference in body height between males and females in the unimplanted and implanted groups, which meant that body height was not the only factor that affected the implantation of inferomedial screws. Neck shaft angle and other parameters may also be crucial factors, which need to be clarified in further studies. Therefore, for tall men, the inferomedial screws should be implanted whenever possible to obtain better medial column support.

There are several limitations to this study. First, the data were obtained from normal humeri., and there were probably some differences when compared with the abnormal humeri. Second, there may be some concerns about additional radiation exposure; it has been reported that specific protocols in combination with filters and image post-processing software may solve the radiation dose problem [35,36]. Lastly, participants were not asked to undergo CT scans of the bilateral humerus. Therefore, the correlation between parameters of the bilateral humerus could not be evaluated.

Conclusions

The differences in screw length and implantation rate of inferomedial screws between males and females and their correlations with body height were shown in this study. Surgeons should pay more attention to choosing the proper screw length and evaluating whether the inferomedial screw can be implanted for short women with proximal humerus fractures. Therefore, our data can be used as a reference for surgeons to reduce the number of times screws need to be changed intraoperatively, as well as reducing operation duration and minimizing use of intraoperative fluoroscopy for proximal humerus fractures treated with the PHILOS plate.

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