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Anatomical mismatch between the proximal humerus and PHILOS plate could result in varus malreduction

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This study aims to investigate the anatomical incongruity between the proximal humerus and the PHILOS plate, which may lead to varus malreduction when this plate is used for indirect reduction. Fifty Asian cadaveric human humeri were included in the study. Three-hole and five-hole PHILOS plates were appropriately positioned on the lateral cortex of the proximal humerus. The gap distance between the plate and the lateral surface of the proximal humerus at each screw hole was measured using a digital vernier caliper. A Kirschner wire was inserted into the humeral head, guided by the locking sleeve. The angle between the plate and the lateral cortex was then measured. Differences in plate–bone distance and angles between the different plate lengths were analyzed using a paired t-test. The correlation between demographic variables and mismatched data was evaluated using Pearson correlation. All measurements were conducted by two observers to assess inter-observer reliability. In all specimens, the maximum gap distance was observed at the most proximal screw hole. The average plate–bone distance at this location was 2 mm for the 3-hole plate and 3 mm for the 5-hole plate. The average plate–bone angle was 2.9 degrees for the 3-hole plate and 3.2 degrees for the 5-hole plate. No correlation was found between total humeral length and either the plate–bone distance or the plate–bone angle. Due to the anatomical mismatch between the PHILOS plate and the proximal humerus, caution is advised when using the plate for indirect reduction, as it may lead to secondary varus malreduction.

Keywords: Proximal humerus, mismatch, PHILOS, varus reduction, implant failure.

INTRODUCTION

In the aging population, proximal humerus fractures represent the third most common type of fragility fracture[1]. These fractures typically result from low-energy falls in the elderly, whereas younger patients often sustain them due to high-energy trauma. Given the wide range of injury severity, treatment options can vary from nonoperative management to surgical fixation or prosthetic replacement[2]. For reconstructable fractures, especially those involving short and osteoporotic proximal fragments, surgical fixation using fixed-angle devices such as the Proximal Humeral Internal Locking System (PHILOS) plate remains the preferred treatment, as it ensures construct stability[2-3]. However, implant-related complications remain relatively common, with reported rates ranging from approximately 6.7% to 37%[4-12], and may lead to additional surgical interventions. Several factors have been identified as poor prognostic indicators for fixation failure, including comminution of the calcar region, loss of medial support, complex fracture morphology, and a history of cigarette smoking[4-12]. Notably, postoperative varus malreduction is regarded as a significant prognostic factor for fixation failure[4,8,10,11].

The PHILOS plate is designed to anatomically conform to the lateral surface of the humeral head and proximal shaft. However, in certain patients, a mismatch may exist between the PHILOS plate and the bone, resulting in a gap between the lateral surface of the proximal shaft and the inner surface of the plate. Consequently, using this plate for indirect reduction of the humeral shaft to the humeral head fragment may lead to malreduction due to the anatomical incongruity between the plate and the bone.

The primary objective of this study was to investigate the anatomical mismatch between the proximal humerus and the PHILOS plate. The secondary objective was to evaluate the correlation between the degree of mismatch and humeral length, as well as between the plate–bone angle and plate–bone distance.

MATERIALS AND METHODS

The study was approved by the Institutional Review Board of the hospital (approval number: LH.62047). Cadavers were selected through a simple randomization procedure. The sample size was calculated using a formula for estimating the mean of an infinite population. Based on the standard deviation from the study by Ravindra et al.13, a margin of error limited to 30%, and an alpha level of 0.05, the minimum required sample size was determined to be 35. Fifty Asian cadaveric human humeri (25 left and 25 right) without obvious deformities were included in this study. Both 3-hole and 5-hole 3.5-mm Proximal Humeral Internal Locking System® (PHILOS, Synthes Depuy GmbH, Oberdorf, Switzerland) plates were securely fixed over the lateral cortex of the proximal humerus, positioned 5 mm below the tip of the greater tuberosity and 2 mm lateral to the bicipital groove, as recommended. The gap distance between the inner surface of the plate and the lateral surface of the proximal humerus was measured at each conventional screw hole along the shaft using a digital vernier caliper; this was termed the "plate–bone distance." A 2-mm Kirschner wire was inserted into the humeral head through a guide sleeve to evaluate for any cortical perforation. Photographs of the bone with the secured PHILOS plate were taken from the anterior and superior aspects of the proximal humerus. The "plate–bone angle" was calculated by measuring the angle between the plate and the lateral cortex of the bone on the anterior photographs, using the ImageJ software (NIH) (Fig. 1). Humeral head retroversion was defined as the angle between the epicondylar axis and a line perpendicular to the articular surface, measured on superior-view photographs. Total humeral length, neck-shaft angle, and the distance from the calcar to the most inferior Kirschner wire were measured from radiographs using a PACS system. Total humeral length was defined as the distance between the most proximal part of the proximal humerus and the most distal part of the distal humeral condyle. The neck-shaft angle was measured as the angle between the axis of the humeral shaft and a line perpendicular to the articular axis. The distance from the calcar to the most inferior Kirschner wire was measured in a

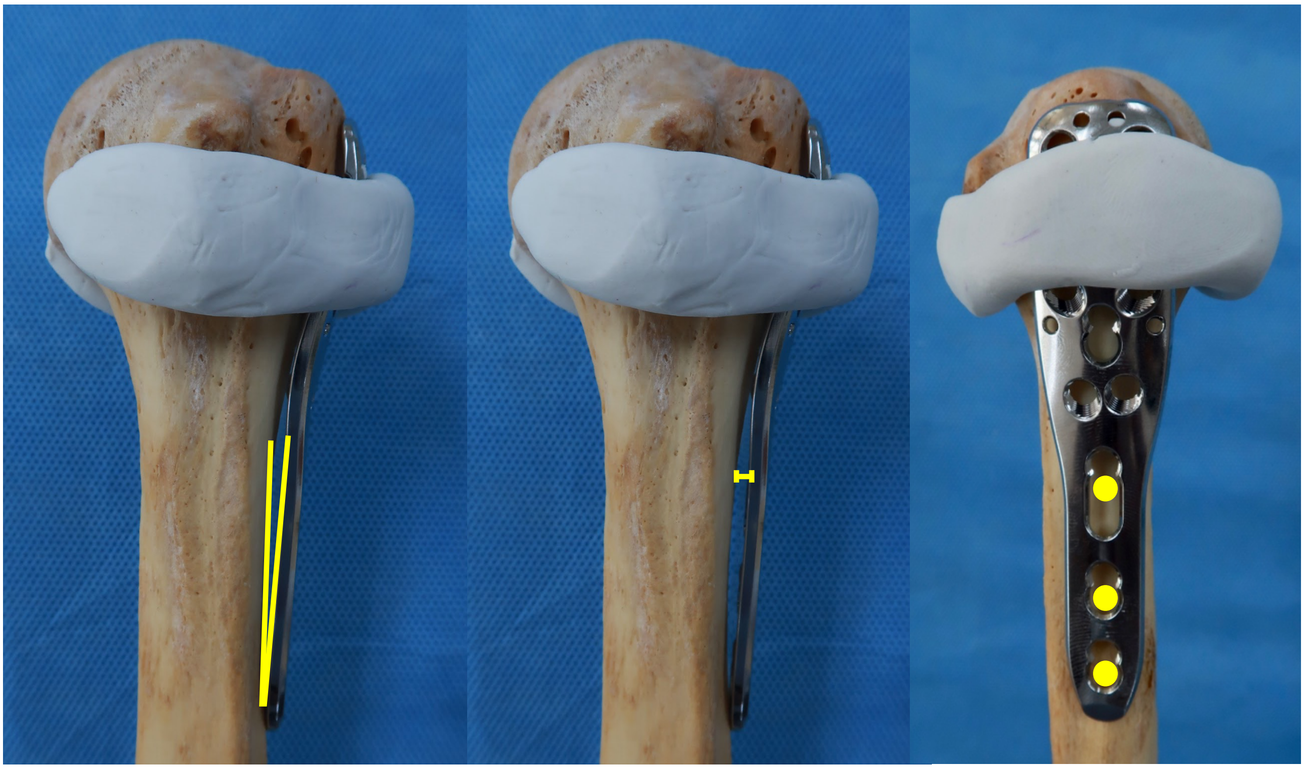

Fig. 1 — An anterior photograph of the proximal humerus with the PHILOS plate in place. The plate–bone angle was measured independently by two orthopedic surgeons using the ImageJ software. The plate–bone distance was measured at each conventional screw hole as the gap between the lateral surface of the humerus and the inner surface of the PHILOS plate using a digital caliper.

plane perpendicular to the Kirschner wire (Fig. 2). All measurements were performed independently by two trauma orthopedic surgeons.

Age, total humeral length, plate–bone distance, and plate–bone angle were reported as mean ± standard deviation (SD). Differences in plate–bone distance and plate–bone angle between the 3-hole and 5-hole plates were analyzed using paired t-tests. Pearson correlation coefficients were calculated to assess the relationships between total humeral length and both plate–bone distance and plate–bone angle. Inter-observer reliability was evaluated using the intraclass correlation coefficient (ICC) with absolute agreement. The average of the two observers' measurements was used for analysis.

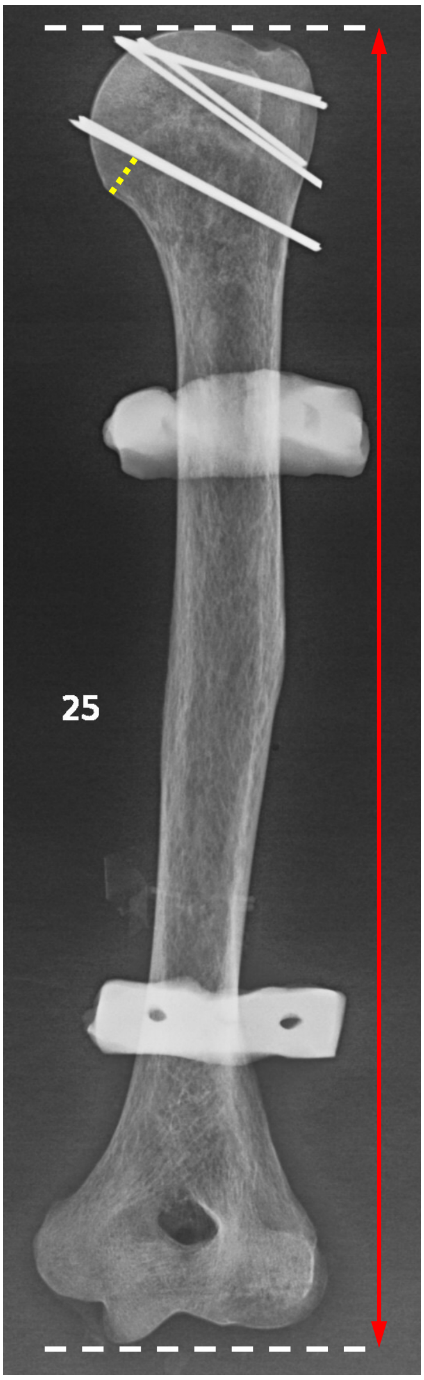

Fig. 2 — Radiographic measurement depicting total humeral length (red line) and the distance from the calcar to the most inferior Kirschner wire (yellow line).

RESULTS

The mean total humeral length, neck-shaft angle, and retroversion were 31 cm (range, 27–35 cm), 134° (range, 123°–145°), and 36° (range, 11.1°–48°), respectively, see Table I.

For plate–bone distance, the most proximal shaft screw hole in all specimens exhibited the greatest gap. In the 3-hole plate, the average plate–bone distance at the most proximal hole was 2 mm (range, 0.04–3.9 mm), while in the 5-hole plate, it was 3 mm (range, 1.1–4.4 mm), showing a statistically significant difference between the two plates ($p < 0.01$). The average plate–bone angle was 2.9° (range, 0.01°–5°) for the 3-hole plate and 3.2° (range, 1.3°–6.3°) for the 5-hole plate. No significant difference was observed in plate–bone angle between the 3-hole and 5-hole plates ($p = 0.22$), see Table II.

The mean distance from the calcar to the most inferior Kirschner wire was 7.4 mm (range, 0.1–16 mm). In two cadavers, the most inferior Kirschner wire penetrated beyond the calcar cortex. No correlation was found between total humeral length and plate–bone distance ($r = 0.08$) or plate–bone angle ($r = 0.09$). All measurements demonstrated good inter-observer reliability, with intraclass correlation coefficients (ICC) exceeding 0.8.

DISCUSSION

In proximal humerus fractures, several risk factors contributing to fixation failure have been identified, including poor bone quality[5,7], smoking[6,9,12], calcar comminution[5-6,9], and loss of medial support[7,8]. Recent literature has emphasized varus malreduction as one of the most significant factors[4,8,10,11], which may subsequently lead to further collapse and screw cut-out from the humeral head. This malreduction can result from inadequate direct fracture reduction or indirect reduction—particularly when using the PHILOS plate—due to the presence of a gap between the plate and bone. A similar effect has been observed with the mismatch between the distal femoral locking plate and distal femoral anatomy in Asians, which leads to valgus malalignment when

Table I. — Demographic data of humeral cadavers.

Characteristic	Value
Age, years; mean (SD)	76.3 (7.5)
Humeral length, cm; mean (SD)	31 (1.9)
Neck-shaft angle, degrees; mean (SD)	134.5 (4.8)
Humeral retroversion, degrees; mean (SD)	36.2 (7.9)

Table II. — Plate-bone distance and plate-bone angle.

Parameters	3-hole plate	5-hole plate	95%CI	p-value
Plate-bone distance, mm; mean (SD)	2 (0.9)	3 (0.8)	-1.3 – (-0.6)	<0.01*
Plate-bone angle, degrees; mean (SD)	2.9 (1)	3.2 (1.2)	-0.7 - 0.2	0.22
*Statistically significant.				

the plate is used to assist reduction[14]. Although anatomical locking plates are designed to conform to human bone, no single design can universally accommodate all anatomical variations. Therefore, a thorough understanding of the specific regional anatomy is essential for successful surgical fixation.

Our study demonstrated a significantly greater gap between the 5-hole PHILOS plate and the bone at the most proximal shaft screw hole compared to the 3-hole plate. This difference may be attributed to the placement of the distal end of the 5-hole PHILOS plate over the deltoid tubercle, whereas the 3-hole plate terminates more proximally, allowing closer apposition to the bone. Additionally, our results showed that the plate–bone angle for the 5-hole plate was slightly larger than that for the 3-hole plate. It is possible that both the gap distance and the angle may be even greater in vivo, where the rotator cuff tendon overlies the greater tuberosity. These findings are consistent with those reported by Ravindra et al. They reported greater bone–plate distance and bone–plate angle for the 5-hole PHILOS plate compared to the shorter 3-hole plate[13]. However, our study observed slightly greater bone–plate distance and bone–plate angle. This discrepancy may be attributed to differences in the ethnic backgrounds of the cadavers used, as Asian specimens may have smaller bone dimensions, contributing to a greater anatomical mismatch with the PHILOS plate. Recently, Kim et al. published an observational study investigating the angulation between the lateral border of the greater tuberosity and the lateral cortex of the humeral shaft, referred to as the "lateral angle" of the proximal humerus[15]. The average lateral angle reported by Kim et al. was 12.9°, ranging from 8.1° to 19.4°. They found a discrepancy between the lateral angle of the proximal humerus and the bending angle of three pre-contoured locking plate designs, which ranged from 8° to 10°, resulting in poor fit of the plates to the proximal humerus anatomy. Notably, 98% of their study population exhibited a lateral angle greater than 8°. These findings correlate with our study, which observed average bone–plate angles of 2.9° for the 3-hole plate and 3.5° for the 5-hole plate.

The anatomical mismatch not only contributes to varus malreduction but also results in loss of medial calcar support due to lateralization of the humeral shaft, as illustrated in Fig. 3. An unreduced calcar is a strong predictor of loss of alignment 16. Despite the minor anatomical disparities between the PHILOS plate and the proximal humerus, this mismatch becomes more pronounced when the metaphysis is comminuted and the shaft is shortened to support the humeral head. Under these conditions, the discrepancy between the diameters of the humeral head and the shaft increases, exacerbating the anatomical mismatch (Fig. 4). The combination of varus malreduction and loss of medial support may significantly increase the risk of fixation failure[17]. Therefore, we strongly recommend the use of intraoperative fluoroscopic guidance when inserting cortical screws for indirect reduction of the shaft fragment to the plate. This approach ensures accurate screw placement and helps maintain an appropriate neck–shaft angle, thereby minimizing the risk of fixation failure. According to the principles of locking plate systems, which function as internal fixators, maintaining a slight gap between the plate and the bone while achieving a high-quality reduction can lead to favorable clinical outcomes—particularly when the anatomical locking plate does not perfectly conform to the patient's specific anatomy. Consequently, a good reduction with a gap between the bone and plate is considered acceptable, whereas a well-contoured bone–plate interface accompanied by malreduction is not.

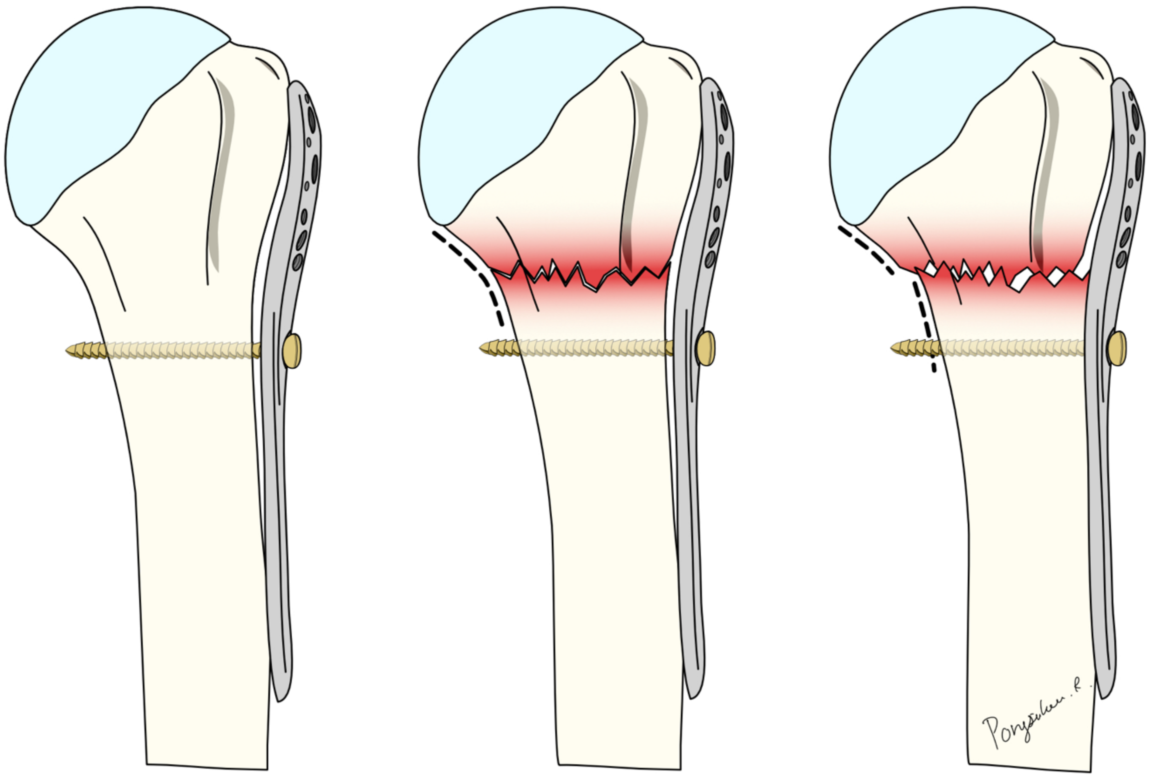

Fig. 3 — Illustration demonstrating the effect of indirect reduction of the humeral shaft in the presence of anatomical mismatch between the PHILOS plate and the bone, potentially resulting in varus malalignment and loss of medial calcar support.

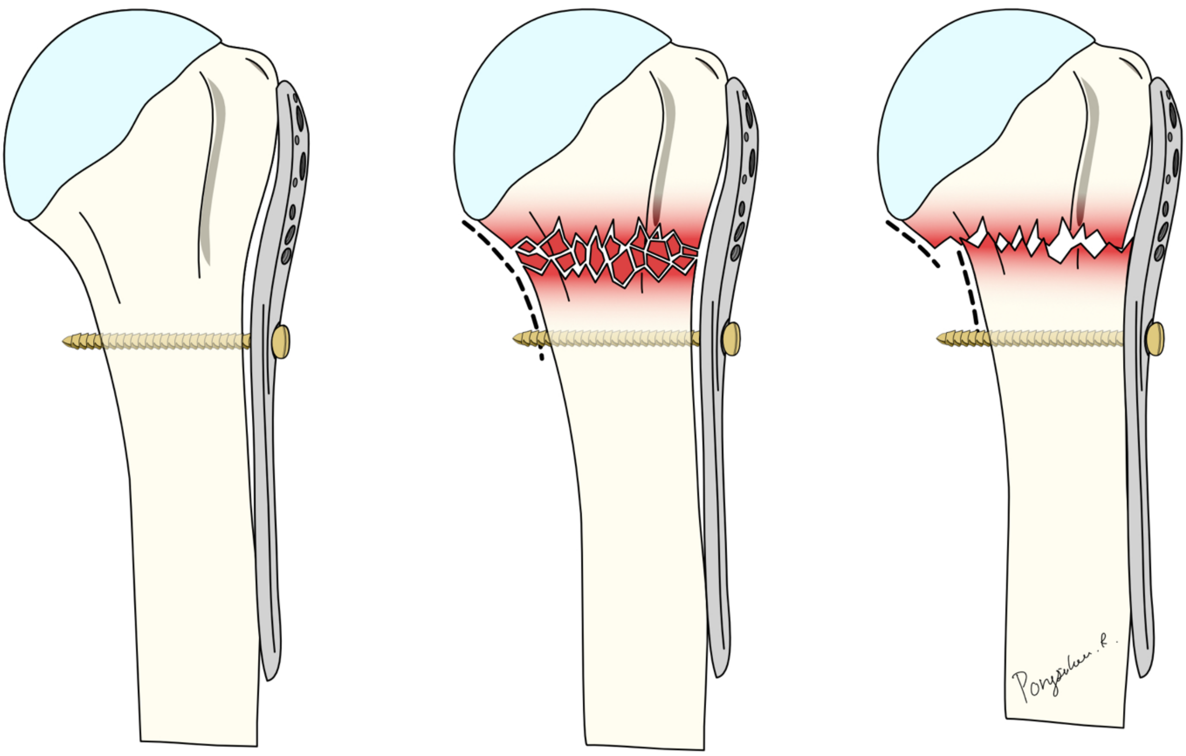

Fig. 4 — Illustration depicting a comminuted metaphyseal proximal humerus fracture. Shortening of the shaft combined with indirect reduction using the PHILOS plate results in an increased mismatch between the diameters of the humeral head and the shaft fragment.

In two cadavers, we observed Kirschner wires inserted through the calcar screw holes penetrating inferiorly beyond the articular surface. This cortical penetration may be attributed to the smaller size of the humeral head commonly found in the Asian population. Additionally, malpositioning of the plate too far cephalad or caudad can lead to calcar screw misplacement. A cadaveric study by Ji-Yong Kwak et al. recommended applying the PHILOS plate in its most anatomically contoured position to minimize such complications[18]. They found that positioning the plate 3.6 millimeters distal to the tip of the greater tuberosity and 2.5 millimeters lateral to the bicipital groove represents the most anatomically contoured placement. Furthermore, Thienthong et al. reported a 3.3% incidence of calcar screw penetration, even when the plate was positioned at the most proximal part of the bicipital groove[19]. Recently, Patel et al. reported that 20% of plates exhibited inappropriate inferior positioning of the calcar screw, particularly in smaller patients when using the greater tuberosity as a reference for PHILOS plate placement[20]. These findings support our study, highlighting that the optimal plate position in Asian populations may differ from the recommendations established for Caucasian patients. Careful attention to proximal–distal plate positioning is essential to prevent calcar screw penetration beyond the articular surface. Intraoperative fluoroscopic guidance is also strongly recommended during calcar screw insertion. Additionally, newer plate designs featuring variable-angle locking screws may allow for better optimization of calcar screw placement.

There are several limitations to our study. First, the use of cadaveric bones without soft tissue attachments does not fully replicate in vivo conditions. In clinical scenarios, the presence of rotator cuff and deltoid muscles may further impede contact between the plate and bone, potentially increasing gap distances and angles. Second, the relatively small magnitude of the bone–plate distance and bone–plate angle measurements may introduce measurement error. To mitigate this, two independent surgeons performed all measurements, resulting in good inter-observer reliability (ICC). Finally, our study was limited to the PHILOS plate system; future research evaluating alternative plate designs may provide additional insights into their compatibility with proximal humerus anatomy. Third, our study did not stratify cadavers by sex; however, previous research has reported significant anatomical differences in the proximal humerus between sexes, which may contribute to anatomical mismatch in plate fixation[21]. Finally, comprehensive biomechanical and clinical studies are needed to further clarify the impact of anatomical mismatch, which can lead to varus malreduction and loss of medial calcar support, particularly in cases involving metaphyseal comminution.

CONCLUSION

The use of the PHILOS plate for indirect reduction of proximal humerus fractures warrants caution due to potential anatomical incongruities between the plate and the bone, which may predispose to secondary varus malreduction. Our study identified a significantly greater mismatch associated with the 5-hole plate compared to the 3-hole variant. Moreover, meticulous insertion of calcar screws is imperative to prevent cortical perforation beyond the humeral head. Precise confirmation of the plate's position along the supero-inferior axis is essential. To mitigate these risks, the application of intraoperative fluoroscopic guidance is strongly advocated to ensure accurate fracture reduction and optimal positioning of both screws and plate during operative intervention.

The study was performed at the institute of orthopaedics, Lerdsin General Hospital.

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