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The neck-shaft angle is the key factor for the positioning of calcar screw when treating proximal humeral fractures with a locking plate

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Aims

The aim of this study was to explore why some calcar screws are malpositioned when a proximal humeral fracture is treated by internal fixation with a locking plate, and to identify risk factors for this phenomenon. Some suggestions can be made of ways to avoid this error.

Methods

We retrospectively identified all proximal humeral fractures treated in our institution between October 2016 and October 2018 using the hospital information system. The patients' medical and radiological data were collected, and we divided potential risk factors into two groups: preoperative factors and intraoperative factors. Preoperative factors included age, sex, height, weight, body mass index, proximal humeral bone mineral density, type of fracture, the condition of the medial hinge, and medial metaphyseal head extension. Intraoperative factors included the grade of surgeon, neck-shaft angle after reduction, humeral head height, restoration of medial support, and quality of reduction. Adjusted binary logistic regression and multivariate logistic regression models were used to identify pre- and intraoperative risk factors. Area under the curve (AUC) analysis was used to evaluate the discriminative ability of the multivariable model.

Results

Data from 203 patients (63 males and 140 females) with a mean age of 62 years (22 to 89) were analyzed. In 49 fractures, the calcar screw was considered to be malpositioned; in 154 it was in the optimal position. The rate of malpositioning was therefore 24% (49/203). No preoperative risk factor was found for malpositioning of the calcar screws. Only the neck-shaft angle was found to be related to the risk of screw malpositioning in a multivariate model (with an AUC of 0.72). For the fractures in which the neck-shaft angle was reduced to between 130° and 150°, 91% (133/46) of calcar screws were in the optimal position.

Conclusion

The neck-shaft angle is the key factor for the appropriate positioning of calcar screws when treating a proximal humeral fracture with a locking plate. We recommend reducing the angle to between 130° and 150°.

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Introduction

Since Gardner et al[1] emphasized the importance of medial support in plate fixation of proximal humeral fractures in 2007, numerous studies have shown that the intraoperative restoration of medial support is related to better final outcomes.[2-6] Several strategies can be chosen to improve medial support, such as inserting calcar screws, implanting a fibular strut allograft, or using a medial plate technique.[3,4,7] The use of calcar screws is the most widely used of these techniques with almost all types of design of proximal humeral plate.[2,5,8-10] It has been shown that complicated fractures treated using calcar screws can achieve more rigid fixation with a decreased risk of loss of reduction compared with those without the screws.[1,2]

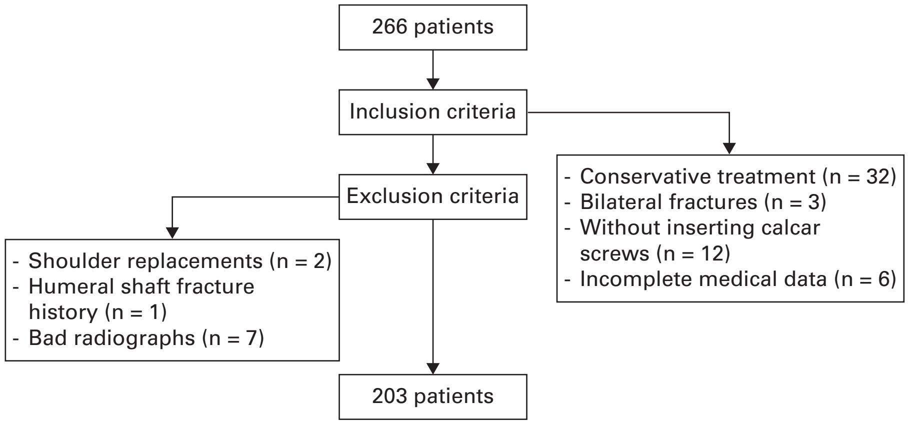

Fig. 1

Patient selection process.

Table I. Demographics and statistical results of preoperative factors.

Variable	Optimal position	Malposition	OR (95% CI)	Adjusted p-value*
Mean age, yrs (SD)	62 (13)	63 (14)	1.006 (0.981 to 1.031)	0.661
Sex, M:F	47:107	16:33	1.078 (0.538 to 2.157)	0.833
Mean height, m (SD)	1.6 (0.1)	1.6 (0.1)	0.384 (0.007 to 21.523)	0.641
Mean weight, kg (SD)	63 (11)	62 (11)	0.531 (0.962 to 1.020)	0.531
Mean BMI, kg/m^2 (SD)	24 (3)	24 (4)	0.986 (0.898 to 1.082)	0.761
Mean proximal humeral BMD, (SD)	0.18 (0.03)	0.17 (0.04)	1.600 (0.010 to 2.513)	0.303
Neer classification, n (%)				0.317
Two-part	47 (30.5)	12 (24.5)	Reference	
Three-part	70 (45.5)	18 (36.7)	1.038 (0.456 to 2.363)	0.930
Four-part	37 (24.0)	19 (38.8)	1.791 (0.751 to 4.269)	0.189
AO/OTA classification, n (%)				0.714
Type A	44 (28.6)	12 (24.5)	Reference	
Type B	66 (42.8)	18 (36.7)	1.049 (0.457 to 2.408)	0.910
Type C	44 (28.6)	19 (38.8)	1.384 (0.585 to 3.277)	0.459
Medial hinge, n (%)				0.672
Intact	100 (64.9)	29 (59.2)	Reference	
Single disruption	25 (16.3)	6 (12.2)	0.810 (0.302 to 2.172)	0.676
Comminution	29 (18.8)	14 (28.6)	1.335 (0.575 to 3.101)	0.501
Head extension, n (%)				0.166
< 8 mm	64 (41.6)	27 (55.1)	Reference	
≥ 8 mm	90 (58.4)	22 (44.9)	0.627 (0.324 to 1.213)	0.166

*Binary logistic regression analysis.
AO/OTA, AO Foundation/Orthopaedic Trauma Association; BMD, bone mineral density; BMI, body mass index; CI, confidence interval; OR, odds ratio.

However, although surgeons have adopted the suggestion of inserting calcar screws, in some cases these screws have been placed too proximally or too distally which means that they are not "real" calcar screws.[8] Recent studies have investigated the optimal position of these screws with similar results to those of earlier studies, concluding that calcar screws should be placed close to the medial calcar, within the inferomedial quarter of the humeral head.[8,11] If the screws are not placed in the optimal position, they can not provide appropriate medial support.

The reasons for the malpositioning of calcar screws and how to avoid this have not been examined. The aim of this study was to identify the risk factors for this phenomenon, and to make recommendations about how it can be avoided.

Methods

All proximal humeral fractures treated in our institution between October 2016 and October 2018 were identified through the hospital information system. All analyses were carried out in accordance with relevant guidelines and regulations of the local ethics committee and we obtained approval for this study (no. 2018-ky-062).

Fractures which met the following inclusion criteria were included in the study: acute unilateral fractures; those treated by open reduction and internal fixation using the same locking plate (Philos plate; DePuy Synthes, Oberdorf, Switzerland); using at least one calcar screw, and with complete medical and radiological records (including preoperative anteroposterior

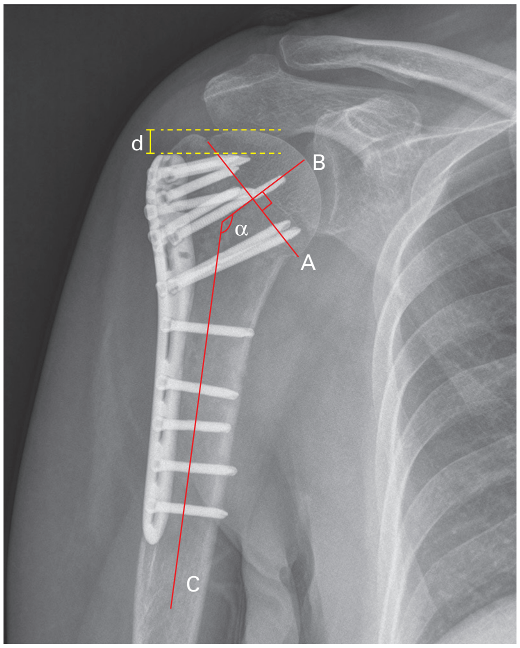

Fig. 2

The method of measuring the neck-shaft angle and the height of the humeral head. Line A was drawn along the border of the articular surface and line B perpendicular to it through the centre of the humeral head. Line C was parallel to the humeral shaft, and the neck-shaft angle was angle α. Two lines (indicated by the yellow horizontal dashed lines) were drawn across the superior borders of the humeral head and the plate. The distance (d) between the two lines was the height of the humeral head.

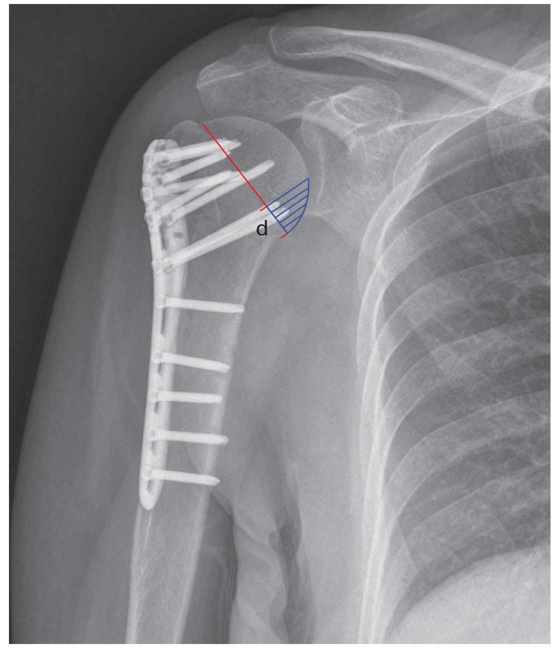

Fig. 3

The dashed area shows the optimal position of calcar screws. The length of the side 'd' equals 25% of the border of the articular surface.

(AP) radiographs and CT scans, and AP radiographs taken on the first postoperative day.

Exclusion criteria included: those being treated with revision surgery; those in patients with previous trauma or surgery involving the same shoulder, and those with radiographs in which the position of the calcar screw could not be clearly identified.

Once a patient was included, their medical and radiological data were extracted from our information system. Details of the inclusion process can be seen in Figure 1. A total of 203 patients were included (63 males and 140 females) with a mean age of 62 years (22 to 89). Calcar screws were considered to be malpositioned in 49 fractures and were in the optimal position in 154. The rate of malpositioning was therefore 24% (49/203). The demographic and statistical details of the preoperative factors are shown in Table I.

We divided potential risk factors into two groups: preoperative and intraoperative factors. Preoperative factors were: age, sex, height, weight, body mass index (BMI), proximal humeral bone mineral density, type of fracture, condition of the medial hinge, and medial metaphyseal head extension. The method used for measuring proximal humeral bone mineral density using the ratio of the medial cortical thickness to the diameter of the humeral shaft has been previously described.[12] The type of fracture was recorded according to the Neer[13] and AO Foundation/Orthopaedic Trauma Association (AO/OTA)[14] classification systems from the radiographs and CT scans. The medial hinges were categorized as either intact (or two-part and displaced by < 2 mm), a simple disruption (two-part and displaced by > 2 mm), or comminuted (with ≥ three fragments).

Intraoperative factors comprised: the grade of the surgeon; neck-shaft angle after reduction; humeral head height; restoration of medial support; and quality of reduction. All operations were performed by well-trained surgeons who were divided into three grades: those with < ten years' experience of shoulder surgery (grade I), those with between ten and 20 years' experience (grade II), and those with > 20 years' experience (grade III). The neck-shaft angle after reduction and humeral head height were measured on the AP radiograph taken on the first day after surgery, as shown in Figure 2. For fractures with simple disrupted medial hinges, the hinge was considered to be restored if the remaining displacement was < 2 mm. If the medial hinge was comminuted before surgery, the medial support could only be restored if additional augmentation was used, such as a fibular allograft or a medial plate. No patient with an intact medial hinge had an additional augmentation. The quality of reduction, as previously described[15], was defined as well-reduced (fullfil the following three criteria: a neck-shaft angle between 110° and 150°; head-shaft displacement of ≤ 5 mm; and greater tuberosity displacement of ≤ 5 mm) or malreduced (failing to meet at least one of these criteria).

Two reviewers (QW, NS) completed the pre- and intraoperative classifications and measurements independently and a third (BR) integrated all the records, with the names of the first two reviewers being blinded to the third. Disagreements would be resolved by the third reviewer (BR).

Our definition of the optimal position for calcar screws was similar to that used in previous studies, in that calcar screws should be placed in the inferomedial quarter of the humeral head (Figure 3). If the screws were not within this zone, they

Table II. Statistical results of intraoperative factors.

Variable	Optimal position	Malposition	OR (95% CI)	Adjusted p-value*
Grade of surgeon, n (%)				0.065
Grade I	31 (20.1)	14 (28.6)	Reference	
Grade II	52 (33.8)	21 (42.8)	0.908 (0.397 to 2.076)	0.820
Grade III	71 (46.1)	14 (28.6)	0.405 (0.170 to 0.966)	0.041
Mean neck-shaft angle, ° (SD)	141 (8)	148 (15)	1.067 (1.030 to 1.105)	0.001
Mean humeral head height, mm (SD)	11 (5)	12 (5)	1.016 (0.950 to 1.086)	0.646
Restoration of medial support, n (%)				0.098
Yes	113 (73.4)	29 (59.2)	Reference	
No	41 (26.6)	20 (40.8)	1.794 (0.898 to 3.585)	0.098
Quality of reduction, n (%)				0.278
Well-reduced	93 (60.4)	23 (46.9)	Reference	
Malreduced	61 (39.6)	26 (53.1)	1.437 (0.732 to 2.964)	0.278
Neck-shaft angle, n (%)†				0.001
Neck-shaft angle <110° or < 150°	140 (90.9)	29 (59.2)	Reference	
Neck-shaft angle ≤ 110° or ≥ 150°	14 (9.1)	20 (40.8)	16.593 (7.148 to 38.518)	0.001
Head-shaft displacement, n (%)†				0.086
≤ 5 mm	102 (66.2)	24 (49.0)	Reference	
≥ 5 mm	52 (33.8)	25 (51.0)	1.816 (0.920 to 3.587)	0.086
Great tuberosity displacement, n (%)†				0.550
≤ 5 mm	139 (90.3)	44 (89.8)	Reference	0.550
≥ 5 mm	15 (9.7)	5 (10.2)	1.438 (0.438 to 4.273)	0.550

*Binary logistic regression analysis.
†These items are subitems of the quality of reduction and dichotomized according to the reduction criteria.
CI, confidence interval; OR, odds ratio

Table III. Statistical results of multivariate model.

Variable	OR (95% CI)	p-value
Grade of surgeon*		
Grade II/I	0.827 (0.347 to 1.968)	0.667
Grade III/I	0.433 (0.171 to 1.097)	0.077
Neck-shaft angle	1.062 (1.025 to 1.099)	0.001
Head-shaft displacement	0.445 (0.130 to 1.518)	0.196
Restore medial support	0.972 (0.277 to 3.408)	0.964

*Grade I surgeon was treated as reference.
CI, confidence interval; OR, odds ratio.

were considered to be malpositioned. We made judgements by checking the AP radiographs taken on the first day after surgery in three rounds by independent reviewers (QW, NS, YC). Each reviewer had three choices of the position of the screws, optimal position, malposition, and poor image, on which the position could not be identified. Any inconsistencies were resolved by discussion with all the authors.

Statistical analysis. All analyses were performed using R software v. 3.5, with the packages 'rms' and 'ROCR' (R Foundation for Statistical Programming, Vienna, Austria). Binary logistic regression was used to identify pre- and intraoperative risk factors, respectively. In order to reduce the bias, preoperative factors were adjusted for the quality of reduction (intraoperative factor) and intraoperative factors were adjusted for the type of fracture (both Neer and AO/OTA classifications, preoperative factor). The factors with $p < 0.1$ were then included in a multivariate regression model using a binary logistic algorithm. Whether calcar screws were in the optimal position was defined as the dependent variable, while potential risk factors were independent variables. The factors with significant p-values were considered as independent risk factors after control of confounders.[16,17] Next, a receiver operator characteristic (ROC) curve was drawn in order to measure the model's discriminative ability by calculating the area under the curve (AUC), which reflects the models' ability to discriminate the position of the calcar screws (optimal or malpositioned). AUC values generally range between 0.5 and 1, with 0.5 indicating no discrimination and 1 indicating perfect discrimination. Results were considered significant when $p < 0.05$, odds ratios (ORs), and 95% confidence intervals (CIs) were calculated for these results.

Results

There were no significant differences between the preoperative factors in the two groups adjusted for the quality of reduction. However, analysis of the intraoperative factors (Table II) showed that the grade of surgeon and neck-shaft angle were related to the risk of calcar screw malpositioning. Grade III surgeons and a well reduced neck-shaft angle were associated with lower rates of malpositioning.

Four variables (grade of surgeon, neck-shaft angle, head-shaft displacement, and restoration of medial support) were included in the multivariate regression model. The results (Table III) showed that the grade of surgeon, head-shaft displacement, and restoration of medial support were no longer considered as independent risk factors when mixed with other factors. Neck-shaft angle was the only significant factor in the model. ROC curves of the mulitvariate regression model and the model only including the neck-shaft angle are shown in Figure 4. The AUCs of the two curves were equivalent when rounded to two decimal places (multivariate model 0.72 vs only neck-shaft angle model 0.72), which indicated 'fair' discriminative abilities and also indicated that the neck-shaft angle was the major contributor in this model.

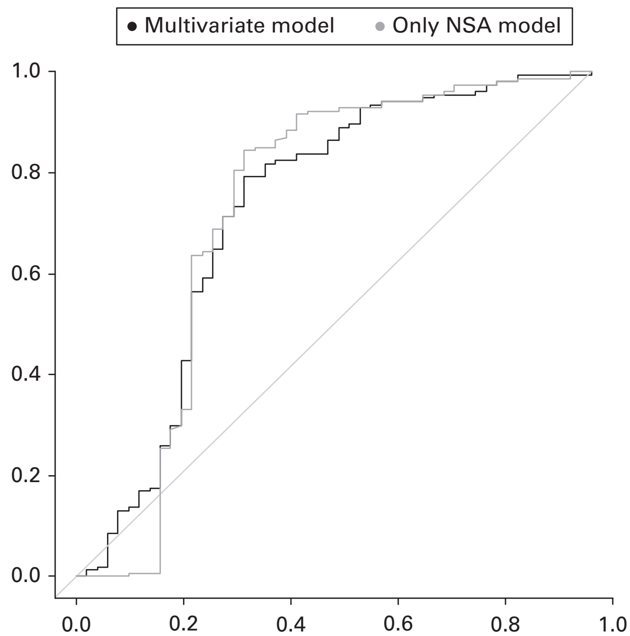

Fig. 4

Receiver operating characteristic curves of the multivariate model and only neck-shaft angle (NSA) model.

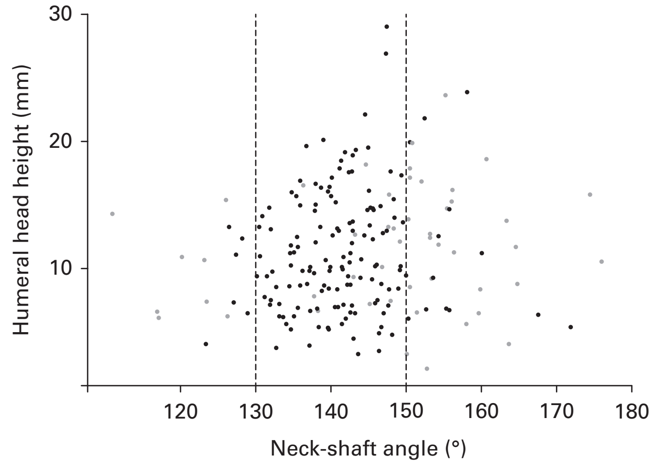

Fig. 5

Diagram showing the distribution of the neck-shaft angles. Each circle represents a patient. A black circle indicates that the calcar screws are in the optimal position; a grey circle indicates malpositioning. The neck-shaft angle of patients with malpositioned screws is clearly different from that of the optimal position group, which are predominantly within the range of 130° to 150°.

The humeral head height and neck-shaft angle data of all the patients were pooled as shown in Figure 5. The distribution of the neck-shaft angle in the patients with a malpositioned screw was clearly different from that in the optimal position group. Those in the malpositioned group were likely to have either a varus or valgus reduced head while a neutral reduced head was likely to be combined with an optimal position of the screws. Furthermore, in the range of 130° to 150°, 91% (133/146) of calcar screws were in the optimal position. In other words, if the angle was reduced to within the range of 130° to 150° during surgery, there was a 91% possibility that the screws would be optimally placed.

Discussion

To the best of our knowledge, this is the first study to report risk factors for malpositioning of calcar screws in these patients. Both pre- and intraoperative factors were included in the study, and the only related factor which we identified was the neck-shaft angle, which if correctly reduced during surgery would significantly reduce the rate of malpositioning of calcar screws. According to the diagram of the distribution of the neck-shaft angles, we recommend that surgeons should reduce the angle to between 130° and 150° during surgery, resulting in a high possibility that the calcar screws could be placed in optimal position.

We are also the first to report the rate of calcar screw malpositioning in clinical practice (24%). This rate was much higher than the rate of complications after the fixation of proximal humeral fractures with a plate,[18] so it should be considered as a major surgical error. We found that the demographics of the patients and the type of fracture had no influence on the position of the calcar screws, which means that the error cannot be related to the type of fracture or the quality of the bone. As long as the neck-shaft angle can be satisfactorily reduced, even in patients with severely osteoporotic bone or complicated fractures, calcar screws could be inserted appropriately. Schnetzke et al[15] reported that the quality of reduction influences the outcomes of AO type C fractures. Zderic et al[19] showed that malreduction was related to the position of the screws and implant failure.[19] However, we did not find that the quality of reduction was related to the position of calcar screws, but the fractures with well-reduced neck-shaft angles (one of the criteria of the quality of reduction) tended to have appropriately placed screws, which has been shown to aid rehabilitation.[8] According to the diagram showing the distribution of the neck-shaft angles, the previous criteria for defining reduction by restoring this angle to between 110° and 150° was not a guarantee of optimal positioning of the calcar screws. From our results, the range of 130° to 150° seemed better (91% vs 87% of the optimal position).

The neck-shaft angle and height of the humeral head are two commonly used criteria which help to evaluate the quality of reduction and fixation when a proximal humeral fracture is treated with a locking plate.[11] The height of the humeral head can also, to some degree, reflect the position of the implant. Clearly, if the plate is placed too proximally or too distally, the calcar screws would be outside the optimal region. Recent studies which reported that the position of calcar screws was related to the strength of fixation, and cadaveric outcomes also assumed that good positioning of the plate would make it easier to place the calcar screws within the optimal area.[8,11] However, we did not find that the humeral head height was related to malpositioning. Our findings were based on clinical cases and all plates were placed in a satisfactory position. No plate was placed much higher than the great tuberosity to prevent subacromial impingement and in no patients did the humeral head height exceed 3 cm. This means that, in practice, most of the calcar screw malpositioning was not attributed to the position of the plate. Inadequate reduction of the neck-shaft angle was the main reason. This inadequate restoration of the neck-shaft angle should be considered in the design of future in vitro biomechanical models of calcar screw malpositioning.

The experience of the surgeon did not seem to be responsible for malpositioning of the screws. According to our univariate adjusted logistic results, the rates of malpositioning associated with different grades of surgeon were significantly different. However, in the multivariate regression model, the significance was lost. This could be explained by the fact that the difference observed by univariate analysis was the result of the influence of the reduction. In other words, the reason why grade III surgeons had a lower rate of malpositioning was because they tended to achieve better neck-shaft angles. It has been previously reported that the learning curve affects the quality of reduction and outcome in orthopaedic procedures.[20–22] Multivariate analysis revealed that reduction of the neck-shaft angle was more important than the experience of the surgeon for the positioning the calcar screws. Thus, as long as the neck-shaft angle was well reduced, the calcar screws tended to be in an optimal position, regardless of the grade of the surgeon.

We also found that restoration of medial support was not an independent factor for the position of the calcar screws. This was an interesting finding because the aim of using calcar screws is to increase medial support. If medial support was not well restored, we could still insert calcar screws in an optimal position and provide medial support appropriately. Previous authors have confirmed that satisfactory clinical outcomes can be obtained by enhancing the medial calcar using screws.[1,2,6,18,23] Our results support the use of this technique in the management of fractures in which it is difficult to restore medial support intraoperatively. It was notable that among the 43 patients with comminuted medial hinges, 30 were augmented with fibular allografts, four with medial plates, and nine without additional augmentation. The procedures involving medial plates were performed by one grade III surgeon and the calcar screws in these patients were all placed in the optimal position. The small number of cases prevents statistical analysis, but whether a medial-plate technique helps to lower the rate of screw malpositioning is worth further study.

This study has limitations. First, it is retrospective with no sample size estimation, and we do not know whether the number of patients is sufficiently large. According to statistical principles, for a study involving four variables, a sample size of 40 would meet the most stringent estimations[24] and we have 49 patients with malpositioning. Secondly, only one type of locking plate was used and it was designed with angle stable screws rather than angle variable screws. However, in many implant designs, calcar screws have a fixed trajectory relative to the plate. This design can provide more rigid fixation as the plate and locked screws have a predefined geometry. Thirdly, some factors which may also influence the position of calcar screws, such as the surgical approach[25] and the diameters of humeral head and shaft,[8] were not included in our analysis. The main reason is that almost all the patients in this study (98%, 199/203) were treated using a routine deltopectoral approach; the other four were treated using an anterolateral delta splitting approach, and the diameters of the humeral head and shaft are not commonly used measurements in routine clinical work.

In conclusion, the neck-shaft angle is the key factor related to the risk of malpositioning calcar screws when undertaking the fixation of proximal humeral fractures with a locking plate. We recommend reducing the angle to between 130° and 150° intraoperatively. No preoperative risk factor was found for calcar screw malpositioning.

Take home message

- Neck-shaft angle is the key factor related to the risk of malpositioning calcar screws while treating proximal humeral fractures with looking plates.
- Restoring neck-shaft angle to between 130° and 150° intraoperatively helps to place calcar screws in optimal postition.

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Author contributions:

Q. Wang: Designed the trial, Collected, analyzed,and interpreted the data, Drafted and approved the manuscript.

N. Sheng: Designed the trial, Collected the data, Revised and approved the manuscript.

B. Rui: Designed the trial, Revised and approved the manuscript.

Y. Chen: Conceived the project, Designed the trial, Revised and approved the manuscript.

Q. Wang and N. Sheng contributed equally to this work.

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Ethical review statement:
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Trial registration number:
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