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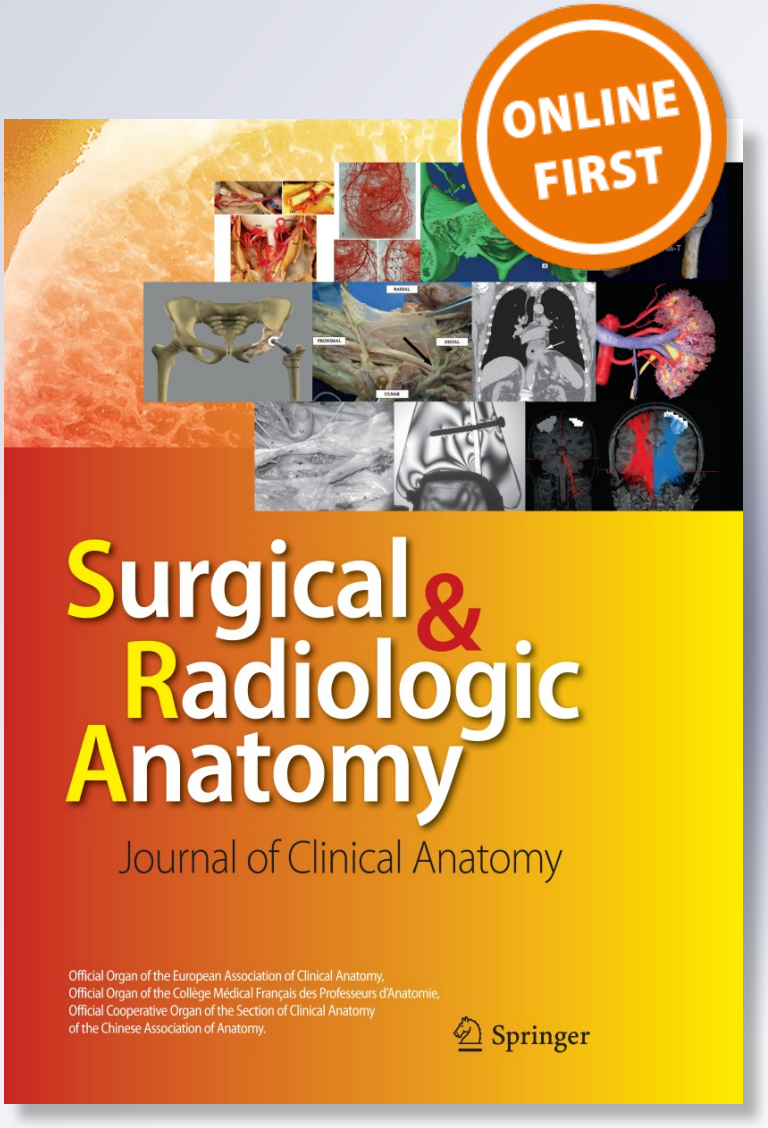

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ORIGINAL ARTICLE

Medial calcar of proximal humeral fracture as landmark in restoration of humeral length in case of hemiarthroplasty

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Abstract
Purpose Several methods to restore the appropriate length of the humerus in the case of proximal humeral fractures treated by hemiarthroplasty have been previously published. Our study evaluates the possibility of using the medial calcar of humerus for humeral length reconstruction not based on preoperative planning.
Methods Preparations of 320 dry humeral bones were used for the purpose of the study. Points of interest were marked on each bone: the most proximal point of the humeral head, the crest of greater tuberosity, diameters of the head, the anatomical and surgical necks. Proximal parts of bones were then scanned from two angles with a digital camera and all measurements were performed on calibrated photographs. We compared accuracy in humeral length reconstruction using insertion of the pectoralis major and the area of medial calcar where usually a fracture develops.
Results The distance between the top part of the humeral head and the insertion of pectoralis major was 54.1 ± 6.0 mm. The distance between the lateral margin of the anatomical neck and the medial calcar was 51.4 ± 4.3 mm. We compared these data with diameters of the humeral head.
Conclusions The site of the fracture can be used for the reconstruction of the humeral length with greater accuracy than area of the pectoralis major insertion. We suggest that to obtain the final distance between the lateral margin of the artificial head and medial calcar of the fracture 2–3 mm should be added to the diameter of the head.

Keywords Fracture of proximal humerus · Calcar of humeral fracture · Reconstruction of proximal humerus · Reconstruction of humeral length · Shoulder arthroplasty · Shoulder hemiarthroplasty

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Introduction

Hemiarthroplasty of the shoulder is an operation used to treat three- and four-part proximal humeral fractures. Absence of the anatomical neck and upper part of the greater tubercle of the humerus as orientation landmarks during the procedure can lead to incorrect positioning of the prosthesis. Incorrect length of the humerus leads to unsatisfactory postoperative outcome [1, 3, 5–7, 10, 16].

Several methods of restoring the appropriate humeral length for arthroplasty have been previously published. The exact length of the injured humerus can be precisely determined and planned on from the non-injured extremity [9]. The technique is based on exact measurement according to the calcar of the fracture prior to the operation. The implant can be set to the proper height in conformity with the greater tuberosity fragment as well [6, 10]. Although surgeons usually plan the procedure (and even

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use jigs) during the operation, some still rely on their experience for humeral length restoration. In such cases the position of the implant is roughly estimated from the shape of the upper part of the shaft fragment.

The required accuracy of the restoration of the humeral length is still unclear. Shortening is better tolerated clinically than lengthening, until it exceeds 15 mm [1, 9]. Other studies were based on these statements and concluded that the length can be restored based on the position of the pectoralis major insertion. The authors, in their anatomical and clinical studies, described the insertion as the reliable landmark for restoration of the humeral length [7, 11, 17].

Our study is based on the anatomical study of reference points of the proximal part of the humerus. We compared the accuracy of humeral length restoration achieved using the medial metaphysis (calcar) of the proximal humerus to the accuracy achieved using the technique based on insertion of pectoralis major muscle.

Materials and methods

For the purpose of the study we used 320 dry preparations of humeral bones (160 left, 160 right) from the collection of Institute of Anatomy, First Faculty of Medicine, Charles University in Prague. Only bones with closed growth plates and no signs of degenerative or post-traumatic alterations were measured from an incipient group of 340 humeri. No information about sex or age of the preparations was available.

Each specimen was inserted into a calibrated steel frame. Bones were scanned with digital cameras (Canon 550D, Lens Sigma 35–70 mm, F3.5) with focal length set to 70 mm. The cameras were positioned three meters from the frame to avoid optical aberration of the lenses.

Each preparation was examined and evaluated separately by two authors before attachment to the frame and bony landmarks were highlighted by graphite pencil on the bone surface (Fig. 1). The anatomical neck, the surgical neck, the top of the humeral head, the medial metaphysis and the most proximal part of the crest of the greater tuberosity were identified.

Two photographs of each proximal humerus were taken (Fig. 1). The first photograph (anterior view) took picture of the anterior surface of the bone with respect to the head retroversion. The axis of the camera lens was set perpendicular to plane defined by the axis of humeral head and axis of diaphysis. The second one (view of humeral head) scanned the humeral head with the axis of the camera lens aligned to the axis of the humeral head.

The anatomical neck was marked by pencil along humeral head margin where cancellous bone of the metaphysis changes into smooth one on the humeral head. Four short line markers were then drawn on the head to designate its biggest and smallest diameter (Fig. 1).

The surgical neck (*S* in Fig. 2) was marked by pencil around the humeral shaft at the level of the CoGT landmark. The medial part of the neck was marked and used for measurements.

The top of the humeral head was defined by its most proximal part (point) and a small cross was drawn at that place.

The crest of the greater tuberosity (CoGT) landmark was marked by a small line in the transverse plane, drawn by pencil on the uppermost part of the clavicular attachment of pectoralis major muscle. The shape and roughness of the bone surface corresponds with shape of the insertion of the muscle. The muscle ends on the crest in a flat tendon (approximately 50 mm wide) consisting of three layers (Fig. 3). The most anterior layer is formed by the clavicular part of the muscle and descends obliquely downward from the clavicle without any rotation into the insertion. This part of the pectoralis major muscle is the thickest one and its insertion can be found on dry bone at a level of the surgical neck. Two other laminas (the sternocostal and the abdominal part of the muscle) form the U shaped part of the tendon passing behind the anterior one. The most posterior (abdominal) part of the insertion extends more superior, almost to the greater tuberosity along the lateral margin of the bicipital sulcus. When the CoGT landmark could not be determined precisely, it was estimated as the midpoint of a range of positions drawn on the clavicular part insertion.

The medial metaphysis (the area of possible fracture) was defined as that part of the proximal metaphysis of the humerus between the most medial point of the surgical neck and the medial margin of the anatomical neck. A short line was drawn in the transversal plane at the area of the cancellous bone where the capsule of the glenohumeral joint is attached. The area was identified with respect to bone openings for vessels, which are usually located at an area where the curvature of the humerus bone changes and the calcar (Fig. 2) of a fracture can develop. Spatial relationships among mentioned landmarks were measured from the two photograph scans using software developed at Faculty of Science, Charles University in Prague.

Distances measured on anterior view (Fig. 2, left):

- The top of the humeral head and the crest of the greater tuberosity parallel to the axis of the humeral diaphysis (*A*)
- The top of the humeral head and crest of the greater tuberosity; absolute distance (*B*)
- The lateral margin of the anatomical neck—the medial metaphysis, area of the capsule insertion (*C*)

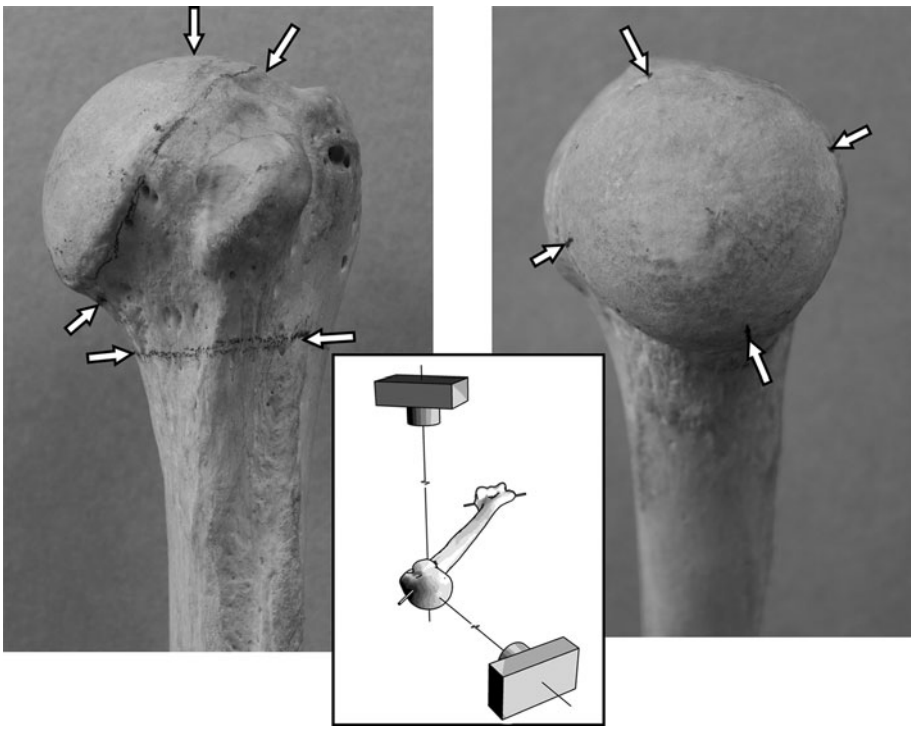

Fig. 1 Photographs of left proximal humerus with points of interest (*white arrows*) and scheme of cameras' position; drawn line by pencil marks most proximal point of the greater tuberosity crest on *anterior view* (*left*); *short lines* drawn by pencil are used to measure the smallest and the biggest diameter of the head on right photograph

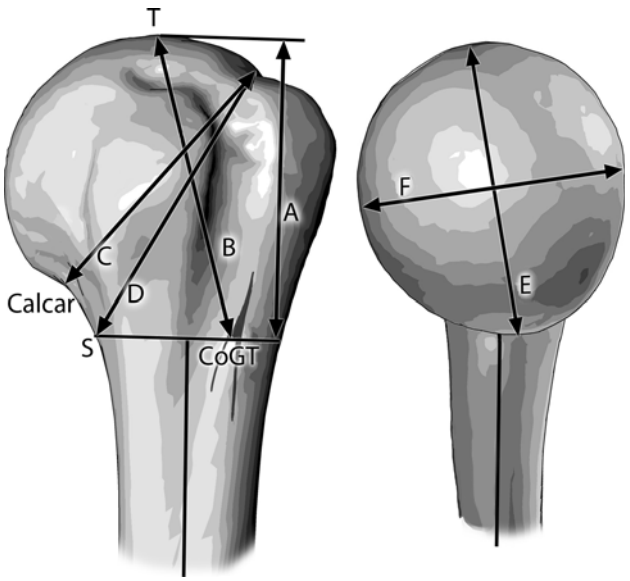

Fig. 2 Scheme of measurement on anterior view and view of the head of the left proximal humerus; *A* distance between the most proximal point of the humeral head and crest of the greater tuberosity landmark in axis of the humerus; *B* distance between the top of the head and the crest of the greater tuberosity; *C* distance between the lateral margin of the anatomical neck and the capsule insertion on medial metaphysis; *D* distance between the lateral margin of the anatomical neck and the medial metaphysis at the level of the surgical neck; *E* the biggest diameter of the head; *F* the smallest diameter of the head; *T* the most proximal point of the humerus

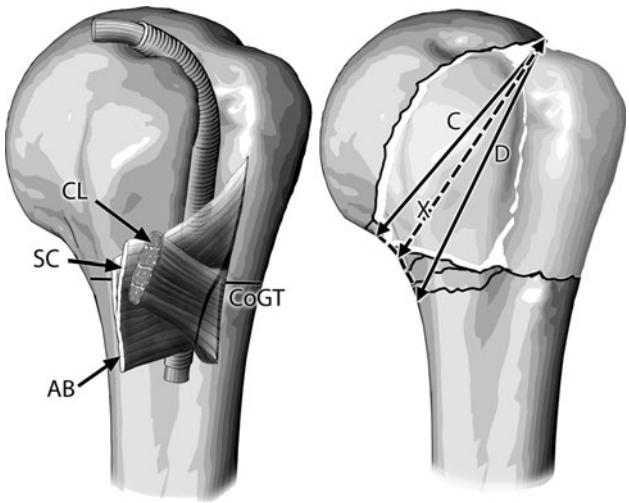

Fig. 3 Anterior view of the left proximal humerus with the insertion of the pectoral major muscle and the tendon of the long head of the biceps on left scheme; *CL* clavicular part of the pectoral major muscle; *SC* sternocostal part; *AB* abdominal part; *CoGT* landmark on the most upper part of the clavicular part attachment; scheme of the four fragment fracture of left proximal humerus; *C* distance between the lateral margin of the anatomical neck and the capsule insertion on medial metaphysis; *D* distance between the lateral margin of the anatomical neck and the medial metaphysis at the level of the surgical neck; *X* virtual distance counted from distances *C* and *D* (see "Mathematical methods")

- The lateral margin of the anatomical neck—the medial part of the surgical neck (*D*) Distances measured on view of humeral head (Fig. 1, right):
- The greatest diameter of the humeral head (*E*)
- The smallest diameter of the humeral head (*F*)

Two authors independently measured proposed distances of the proximal humerus. We used bootstrapping to evaluate interobserver variability. Positions of reference points on each picture were further evaluated using custom made software developed at Faculty of Science, Charles University in Prague.

Mathematical methods

We compared variances of measured distances to evaluate the accuracy of the reconstruction of humeral length. The variances were first computed for the left and right side and for bones with difficult and clear definitions of the crest of the greater tuberosity landmark separately. Final results were then pooled together from both sets of measurements.

Virtual distance *X* has been set up to defined the position of lateral margin of the anatomical neck to the fracture on the medial metaphysis according (Fig. 3). The algorithm of the software calculated the virtual distance from values of distances *C* and *D*.

$$\begin{aligned}\mathrm{var}(X) &= 1/3(\mathrm{var}(C) + \mathrm{var}(D) + \mathrm{covar}(C, D)) \\ &\quad + 1/12(E(C) - E(D))^2\end{aligned}$$

where *E(C)*, *E(D)* are the expected values of distances *C* and *D*. Finally, we used bootstrapping to evaluate the data as to whether the area on the medial metaphysis (area where the fracture developed, distance *X*) could be used for reconstruction of the humeral length as reliably as the landmark of the crest (the insertion of the pectoral major, distance *A*).

Results

Two authors measured the distances among anatomical landmarks of the humeral head and landmarks of the proximal humeral shaft on a defined frontal view of the proximal humerus and the view of the humeral head. Final results were pooled from both sets of measurements (Table 1).

The distance between the top part of the humeral head and the crest of the greater tuberosity was 54.1 ± 6.0 mm (mean ± STD; range, 39.7–62.3 mm) in line of the proximal humeral shaft (*A*) and direct distance between those landmarks (*B*) was 56.4 ± 6.0 mm (range, 42.7–64.2 mm). The distance between the lateral humeral margin and area of the capsule insertion on medial metaphysis (*C*) was 51.4 ± 4.3 mm (range, 42.7–55.6 mm) and the distance between the lateral margin and medial part of the surgical neck (*D*) was 54.5 ± 4.4 mm (range, 45.0–57.4 mm). The diameters of the humeral head were measured on the humeral head view. The proximo-distal diameter *E* was 47.9 ± 4.0 mm (range, 39.3–52.0 mm) and anterio-posterior diameter *F* was 42.1 ± 3.6 mm (range, 33.1–43.0 mm). We did not find any statistically significant difference in interobserver variability of all measured distances.

The humeral length can be calculated more precisely using the medial metaphysis (distance *X*), when compared with the attachment of the crest landmark (distance *A*) [$1.96x$, $p < 0.001$, CI = (1.6617, 2.3366)].

We compared the distance *X* (calculated from distances *C* and *D*, see "Mathematical methods") to the average size of the humeral head (calculated from diameters *E* and *F*) for each bone to set up a recommendation for humeral length reconstruction. We found that if the distance between any point on the medial metaphysis and lateral margin of humeral head was equal to the head diameter +2.5 mm, the result did not exceed the interval −13 to 0 mm of original humeral length (see scatter plot, Fig. 4).

Discussion

Hemiarthroplasty of the shoulder joint is one of the options in case of three or four-part fractures of the proximal humerus. The setup of the prosthesis position, especially its artificial head, is an important part of the operation. Humeral length and humeral head version are the two main parameters of the prosthesis setup [3, 6, 8–10, 15]. An incorrect position of the prosthesis leads to inappropriate reconstruction of tuberosities and difficulties of their fixation [1, 6, 7]. Postoperative malposition and migration of tuberosities results in superior migration of the prosthesis on X-rays, stiffness and pain of the shoulder. Solid and anatomical reconstruction of tuberosities with attachments of rotator cuff muscles is critical for the bone healing process, rehabilitation, and general outcome of the operation [1, 7, 16].

The proper positioning of the implant has been discussed over a long period of time [1, 2, 12, 13]. The suitable range of positions of the top part of the prosthesis is quite wide. Shortening of the humerus is much better tolerated clinically and the functional result is not altered until the shortening exceeds 15 mm [1, 14]. Lengthening of the humerus can be critical and it can significantly affect postoperative outcome. Cranial position of implant can potentially cause difficulties in the greater tuberosity healing and increases tension of the supraspinatus muscle [1]. We think that the humerus should not be prolonged in

Table 1 Distances measured on anterior view of proximal humerus and view of humeral head

	Midpoint of the interval on CoGT	Exact position of CoGT	All
A	53.5 ± 5.8 mm (41.6–68.5 mm)	54.3 ± 6.1 mm (39.7–75.2 mm)	54.1 ± 6.0 mm (39.7–75.2 mm)
B	55.8 ± 5.8 mm (43.4–71.9 mm)	56.6 ± 6.0 mm (42.7–77.0 mm)	56.4 ± 6.0 mm (42.7–77.0 mm)
C			51.4 ± 4.3 mm (42.7–62.3 mm)
D			54.5 ± 4.4 mm (45.0–67.3 mm)
E			47.8 ± 4.0 mm (39.3–57.7 mm)
F			42.1 ± 3.6 mm (33.1–51.3 mm)

A distance between the top of the humeral head and crest of the greater tuberosity in axis of proximal humerus; *B* distance between the top of the humeral head and crest of the greater tuberosity landmark; *C* distance between the lateral margin of the anatomical neck and medial metaphysis; *D* distance between the lateral margin of the anatomical neck and medial metaphysis at the level of the surgical neck; *E* cranio-caudal diameter of the humeral head; *F* anterio-posterior diameter of the humeral head (see "Materials and methods" for details)

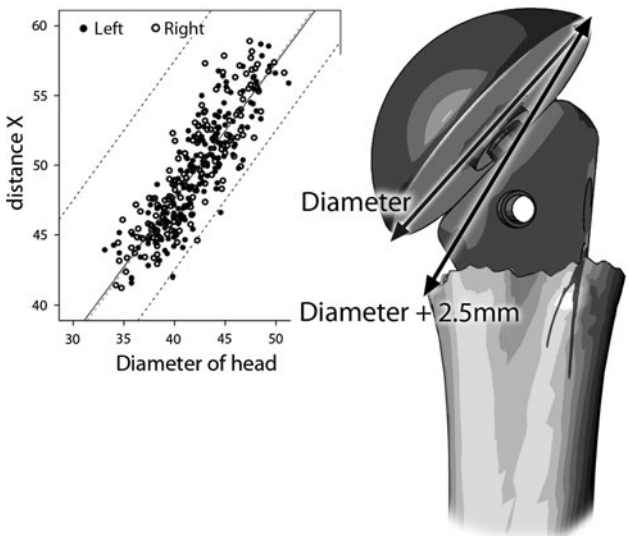

Fig. 4 Correlation between the artificial head diameter and expected distance between the fracture on medial metaphysis and the lateral margin of the head; *dashed lines* bounding interval −15 to +0 mm of original humeral length (*scatter plot*); Recommendation for reconstruction of the humeral length, the distance between the lateral margin of the head to calcar of the fracture should be about 2–3 mm longer than diameter of the head

the reconstruction, but even more important is the relative position of the top of the implant to the upper part of the greater tuberosity.

Boileau and Walch [4] used a jig to set up the proper length of the destructed bone, which can be measured on the contralateral side. Krishnan [9] describes a method that measures the distance from the medial margin of the fracture on the proximal humeral shaft of the injured humerus and the whole length of humerus on the contralateral side. The difference of these distances is then used in prosthesis height setup. We think that the most precise method for individualized reconstruction is preoperative planning on the uninjured arm. Deviations in the length of the humeral bones between the sides are minimal [15].

The insertion of the pectoralis major muscle was also referred to as a landmark for restoring humeral length [7, 11, 17]. The technique is not individual. Murachovsky [11] measured the distance from the upper margin of the pectoralis major insertion (PMT) to the upper part of the humeral head on 20 fresh cadavers. The mean distance was 5.6 ± 0.5 cm (range, 5.0–7.0 cm) with a confidence level of 95 %. Greiner [7] operated on 30 patients utilizing this distance and concluded that the group of patients in which humeral length was restored using pectoralis major insertion as a landmark, showed significantly better clinical outcome and radiographic values than in group of patients with any measurement. The clinical outcome significantly depended on the greater tuberosity healing as evaluated on X-rays. Torrens [17], in an anatomical study on 20 humeri, described the possibility of the pectoralis major muscle insertion as a landmark in the humeral height and retroversion setup. Results showed that the average distance from the insertion to top of the head was 5.64 cm (range, 5.29–5.99 cm). He suggests implanting the prosthesis at 5.6 cm from the upper border of the insertion. The expected difference between the original and restored position will be less than 1 cm in 85 % of the cases i.e. prosthesis position will have a range of 2 cm in 85 %.

The well known distance for PMT landmark was uses in our study to compare with the calculated distance between the medial calcar and lateral margin of the humeral head (see distance *X*, "Mathematical methods"). Comparing previous anatomical studies with our study we do not disagree with those findings. The average distance for PMT landmark was 54 ± 6.0 mm in our study with absence of the humeral cartilage.

Accuracy in the humeral length reconstruction using the upper part of the PMT as the landmark depends on the precise determination of its position. In some cases, however, the exact location of the insertion can be problematic. The insertion itself is about 5–7 cm wide and only the insertion of the clavipectoral part should be used as the landmark during the operation. Muscle fibers of the

clavipectoral part attach directly to the humerus bone, forming a short tendon, in contrast to the deep parts which form a flat aponeurotic attachment. The deeper layers are attached more proximal than the superficial clavipectoral one (Fig. 3). Layers of the insertion can be flat, connected to each other and their crossing can be unclear. The anterior lamina is the thickest and its muscle fibers can be clearly visible in a surgical approach. The landmark for humeral length restoration should be on upper edge of the insertion. Nevertheless, in some cases the lamina is thin and merges with deeper laminas.

The proximal humeral fracture above the surgical neck breaks the cortical bone in a relatively small area on the medial side in contrast to the broad area of the greater tuberosity on lateral side. During the operation it can be difficult to define landmarks precisely. The margin of the fracture on the medial metaphysis is easier to define than the top part of the clavipectoral part's insertion or the lateral margin of the humeral head.

We compared measured distances between the medial metaphysis and the lateral margin of the humeral head and proposed a recommendation according to artificial head size. If a longer humerus in reconstruction is not desired (-13 to $+0$ mm of the original length), the distance between the lateral margin of the artificial head and the fracture on medial metaphysis should be 2–3 mm longer than the diameter of the head (Fig. 4). If a surgeon decides to place the top part of the humerus to range between -8 and $+5$ mm of the original length, the distance should be longer by 7–8 mm than the diameter of the artificial head. These suggestions are proposed for fractures above surgical neck. They use the diameter of the artificial humeral head to be more individualized than a setup according to PMT insertion. Nevertheless, the suggestion can be useful in setup of the implant to the range of the original position; even more accurate result can be obtained by using preoperative measurement of the unaffected arm.

Conclusion

The medial margin of the proximal humeral fracture can be used for the reconstruction of the humeral length with greater accuracy than the insertion of the pectoralis major muscle, but cannot substitute for preoperative planning. It may be considered to optional parameter in humeral length reconstruction. We suggest that to obtain the final distance between the lateral margin of the artificial head and medial calcar of the fracture 2–3 mm should be added to the diameter of the head in that case.

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Conflict of interest None of the authors, or any member of their family, have received any financial remuneration related to the subject of the article.

Ethical standards Experiments in the study comply with the current laws of the country in which they were performed.

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