The medial periosteal hinge, a key structure in fractures of the proximal humerus

A BIOMECHANICAL CADAVER STUDY OF ITS MECHANICAL PROPERTIES

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The medial periosteal hinge plays a key role in fractures of the head of the humerus, offering mechanical support during and after reduction and maintaining perfusion of the head by the vessels in the posteromedial periosteum. We have investigated the biomechanical properties of the medial periosteum in fractures of the proximal humerus using a standard model in 20 fresh-frozen cadaver specimens comparable in age, gender and bone mineral density. After creating the fracture, we displaced the humeral head medial or lateral to the shaft with controlled force until complete disruption of the posteromedial periosteum was recorded. As the quality of periosteum might be affected by age and bone quality, the results were correlated with the age and the local bone mineral density of the specimens measured with quantitative CT.

Periosteal rupture started at a mean displacement of 2.96 mm (SD 2.92) with a mean load of 100.9 N (SD 47.1). The mean maximum load of 111.4 N (SD 42.5) was reached at a mean displacement of 4.9 mm (SD 4.2). The periosteum was completely ruptured at a mean displacement of 34.4 mm (SD 11.1). There was no significant difference in the mean distance to complete rupture for medial (mean 35.8 mm (SD 13.8)) or lateral (mean 33.0 mm (SD 8.2)) displacement ($p = 0.589$).

The mean bone mineral density was 0.111 g/cm³ (SD 0.035). A statistically significant but low correlation between bone mineral density and the maximum load uptake ($r = 0.475$, $p = 0.034$) was observed.

This study showed that the posteromedial hinge is a mechanical structure capable of providing support for percutaneous reduction and stabilisation of a fracture by ligamentotaxis. Periosteal rupture started at a mean of about 3 mm and was completed by a mean displacement of just under 35 mm. The microvascular situation of the rupturing periosteum cannot be investigated with the current model.

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Following fracture of the proximal humerus the extent of the displacement of the humeral head relative to the shaft determines the integrity of the medial periosteal hinge. Preservation of this structure may provide some mechanical stability and allow passive reduction of the fracture.¹ Additionally, the medial hinge can maintain the blood supply of the head fragment.^{2,3} Anatomical studies using arterial injections have found that perfusion of the head can be maintained through small branches of the posterior circumflex artery within the posteromedial periosteum.^{4,5} Hertel et al⁶ concluded from a clinical study that perfusion of the head fragment was only preserved when a segment of the calcar, the posteromedial extension of the head, > 8 mm remained attached to the head. The biomechanical characteristics of the medial periosteum are not well defined. In a non-peer-reviewed report it

has been postulated that the magnitude and direction of displacement of the humeral head seems to influence the integrity of the posteromedial periosteum.⁷

The aim of this study was to simulate a fracture of the humeral head below the anatomical neck with a calcar segment of reproducible length and to determine the displacement and force required to rupture the periosteum. We also wished to assess the effect of age and bone mineral density on the biomechanical properties of the periosteum.

Materials and Methods

We used 20 fresh-frozen human humeri acquired from subjects with a mean age of 72.4 years (43 to 89), of which 12 were male and eight female. Specimens were dissected leaving the muscle attachments intact. The shoulder capsule was divided as far from its insertion into

Fig. 1

Photograph showing test set-up in the material testing machine with the 3D movement analysis system and the load cell incorporated. White arrows indicate the two degrees of freedom permitted by the x-y table.

the humerus as possible for maximum preservation of the medial soft-tissue envelope.

Prior to testing, a quantitative CT scan of all specimens was performed to assess the bone mineral density (BMD) and to exclude bony pathology. Specimens were stored at -20°C and thawed at 4°C for 12 hours before testing, and randomly assigned into two groups for medial or lateral displacement. Each group consisted of six male and four female specimens. The mean age of those selected for lateral displacement was 74.1 years (64 to 89) with a mean BMD of 0.106 g/cm^3 (0.064 to 0.155). The medial displacement group had a mean age of 70.7 years (43 to 89) with a mean BMD of 0.117 g/cm^3 (0.066 to 0.172).

The fracture models described in the literature did not seem appropriate for the purpose of the study, as they all used a complete osteotomy and sacrificed the medial soft tissue.⁸⁻¹³ We devised a new model with a complete bony rupture but intact medial soft tissues using 18 specimens in a pilot series. It was found that a valgus fracture model gave a reproducible calcar fracture with preservation of the periosteum.

In order to be able to create a predetermined fracture line with a reproducible length of calcar segment without injuring the medial periosteum, 20 dissected humeri were investigated. The location and number of the blood vessels entering the medial cortex via the foramina nutriciae at the anatomical neck were used to determine the area of the periosteum that should be left intact during creation of the fracture. In order to compensate for different

humeral sizes, the area was normalised, based on the circumference of the medial centre of the humeral head, the most inferior point of the head and 18% anteriorly and 18% posteriorly.

In order to create the fracture this area was marked with two Kirschner wires 5 mm below the anatomical neck. The remaining dorsal part of the circumference of the head-neck junction was cut with an oscillating saw. Distal to the saw cut a wedge 10 mm in height was removed to create a predetermined breaking point.

The distal ends of the humeri were cut to a standard length of 25 cm. In order to mount the specimen in the test set-up the proximal articulating surface and distal ends were embedded in polymethylmethacrylate (PMMA) cement (Technovit 3040, Heraeus Kulzer, Werheim, Germany).

The testing. The biomechanical testing was conducted in a servohydraulic material testing machine (852 Mini Bionix II, MTS, Eden Prairie, Minnesota). The specimens were fixed in a custom-made jig mounted on an x-y table to minimise shear forces. The jig allowed rotation of the humeral head in the anteroposterior (AP) axis through the centre of the head, which could be blocked after creation of the fracture (Fig. 1). For data acquisition a load cell 1000 N Kraftmessdose type KAT-S (AST GmbH, Dresden, Germany) and an ultrasound-based three-dimensional movement analysing system (Winbiomechanics, Zebris, Isny, Germany) were integrated in the test system. Force and displacement data were recorded with a sampling rate of 100 Hz.

Fracture simulation. In all specimens a valgus fracture of the humerus was created approximately 12 mm distal to the anatomical neck. The head was loaded with a controlled displacement of 20 mm/min until a fracture occurred, while rotation of the head in the AP axis was allowed (Fig. 2).

Rupture of the periosteum. After creating the fracture the head was restored to its intact position and rotation in the AP axis was blocked. The head fragment was then loaded with controlled displacement of 20 mm/min in a medial ($n = 10$) or lateral ($n = 10$) direction until the medial periosteum at the calcar segment was disrupted.

After rupture of the periosteum the length of the calcar segment was measured and documented. From the recorded data load-displacement diagrams were obtained and analysed to identify the load and corresponding displacement at the start of the periosteal rupture, and the maximum load at the moment of complete rupture.

Statistical analysis. This was performed using the SPSS software package 15.0 (SPSS Inc., Chicago, Illinois). Data were tested for distribution using the Kolmogorov-Smirnov test. In order to analyse for differences in normally distributed values the *t*-test was used. Correlation of BMD with maximum load and age was analysed using a bivariate Pearson's test. The level of significance was set at $p < 0.05$.

Fig. 2a

Fig. 2b

Photograph showing fracture creation in the loading jig showing a) the intact specimen and b) the fractured specimen. The white arrow indicates the displacement direction and the black arrow shows the rotation of the head allowed during fracture creation.

Table I. Descriptive values for medial and lateral displacement of the humeral head fragment.

	Medial displacement		Lateral displacement	
	Number	Mean (SD)	Number	Mean (SD)
Age (yrs)	10	70.7 (13.49)	10	74.1 (9.4)
Bone mineral density (g/cm ³)	10	0.117 (0.037)	10	0.106 (0.035)
Length of calcar segment (mm)	10	12.7 (2.6)	10	12.6 (3.3)
Displacement at start of the periosteal rupture (mm)	10	2.4 (2.7)	10	3.4 (3.16)
Load at start of the periosteal rupture (N)	10	85.16 (41.9)	10	116.6 (48.8)
Displacement at maximum load (mm)	10	6.0 (4.9)	10	3.9 (3.2)
Maximum load (N)	10	103 (37.7)	10	119.7 (47.2)
Displacement at completed periosteal rupture (mm)	10	35.88 (13.8)	10	33 (8.24)

Fig. 3

Graph showing the correlation between maximum load uptake and bone mineral density.

Results

For all specimens periosteal rupture started at a mean displacement of 2.96 mm (SD 2.92) at a mean load of 100.9 N (SD 47.13). The mean maximum load of 111.4 N (SD 42.5) was reached at a mean displacement of 4.9 mm (SD 4.2).

The periosteum was completely ruptured at a mean displacement of 34.4 mm (SD 11.17). Regarding the two directions of displacement, medial displacement lead to full rupture at a mean distance of 35.8 mm (SD 13.8), whereas lateral displacement ended at a mean distance of 33 mm (SD 8.2). None of the measured parameters of load and displacement at the start and after complete rupture were statistically significant between the two directions of displacement ($0.139 < p < 0.589$). Descriptive values for both directions are given in Table I.

Study of the 20 dissected specimens revealed that the nutrient foramina responsible for the vascularity of the humeral head extended distally along the medial cortex for a distance of 40 mm to 55 mm depending on the overall size of the humerus. Applying the normalisation based on the circumference of the anatomical neck this involved 36% (SD 4) of that circumference.

The mean BMD was 0.111 g/cm³ (SD 0.035). A statistically significant correlation between BMD and the maximum load uptake ($r = 0.475$, $p = 0.034$), as well as between BMD and age ($r = -0.715$, $p = 0.0001$) was observed (Fig. 3). No correlation was found between age and maximum load

uptake ($r = -0.383$, $p = 0.1$). The distances at the beginning and endpoint of rupture were not statistically related to BMD. Furthermore, it was found that specimens younger than 70 years had a higher BMD ($p = 0.0001$) and a higher maximum load ($p = 0.016$) than specimens of 70 years and older. The age of 70 years was chosen as the cut off as this was the median age of the investigated samples.

Discussion

Periosteal bridges between the head fragment and the shaft can preserve the blood supply of the head in complex fractures.^{2,3} In this study we found that periosteal rupture starts after displacement of the humeral head fragment of approximately 3 mm, and is completed after a displacement of approximately 34 mm, without any significant difference between medial or lateral displacement. This contrasts with the results of Resch and Hubner,⁷ who found a significant difference between medial or lateral displacement of the head fragment, with the periosteal rupture commencing at 9 mm and 6 mm displacement, respectively. The difference in the results can probably be explained by the difference in the experimental models. Resch and Hubner⁷ did not describe their method of fracture creation prior to displacement of the humeral head, how the head segment was displaced, or how the start of periosteal rupture was assessed, as no load was recorded during head displacement.

Our pilot study established that creating a breaking point 5 mm distal to the anatomical neck reproducibly caused a fracture with a medial calcar extension > 8 mm.

Reproducibility of the length of the calcar segment was considered important, as several studies have shown a correlation between its size and its influence on the vascularity of the head fragment,³⁻⁶ including the site of some of the foramen nutriciae. All the fracture models found in the literature are based on full osteotomies of the proximal humerus.⁸⁻¹³

A limitation of our study was that we tested only with medial and lateral displacement, not allowing ante- or retroversion during creation of the fracture and displacement of the head. Therefore, the effect of combined displacements could not be investigated. Also, the size of the calcar fragment was not exactly the same in all samples, leaving some uncertainty about the influence of the length of attached periosteum on the disruption of the blood supply.

There is a lack of information correlating the mechanical properties of the periosteum with the BMD. The correlation between BMD and load uptake shown in this study is low. Considering the thick periosteum found in children and the thin and fragile material seen intra-operatively when treating elderly patients, a strong correlation might be anticipated. Further studies with a larger sample size are required to investigate this further.

Bone quality influences the bone implant interface performance, as shown in biomechanical studies.¹⁴⁻¹⁶ Scientific evidence of the influence of the BMD on fracture fixation is still lacking,¹⁷ but most surgeons managing osteoporotic

fractures are familiar with possible problems of fixation in low-quality bone. The ligamentotaxis effect can provide mechanical support in reduction and stabilisation of a fracture until healing is achieved.^{1,7,18,19} In this study the mean maximum load uptake prior to periosteal rupture was 111.4 N, supporting the use of ligamentotaxis. However, it is not known whether the blood vessels in the posteromedial soft tissue would rupture before the periosteum tears. Finally, radiological assessments of fracture characteristics are conducted on plain films, which provide no information on the maximum displacement that occurred during the trauma. Therefore, determination of periosteal integrity on the basis of displacement on plain radiographs is unrealistic.

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