Fixation of humeral surgical neck fracture using contoured pins versus straight pins: a mechanical study

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Received: 21 July 2006 / Revised: 15 August 2006 / Accepted: 17 August 2006 / Published online: 17 October 2006
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Abstract The conventional procedure for displaced fracture of the surgical neck of the humerus uses straight pins inserted from the lateral aspect towards the head of the humerus. The objective of this study was to compare the mechanical properties of fixation by contoured (curved) pins to those fixed with regular straight pins. A transverse osteotomy was made in 30 fresh-frozen sheep humeri in the proximal metaphyseal bone region, and pins were inserted using either three parallel straight pins or three contoured pins in different planes. The assemblies were subjected to bending or rotational stresses at the fracture site. Loads versus deformations were acquired during loading and rigidity was calculated. Results showed that in bending, fixation with straight pins was 31% more rigid compared to contoured pins ($p < 0.001$), and in torsion, fixation using contoured pins was 21% more rigid compared to straight pins ($p < 0.001$). A combination of the two fixation types should be considered.

Résumé Le procédé conventionnel d'ostéosynthèse des fractures déplacées du col chirurgical de l'humérus utilise des broches rectilignes introduites par la face latérale en direction de la tête humérale. Le but de cette étude était de comparer l'utilisation de broches pré-formées et des broches rectilignes. Une ostéotomie transversale métaphysaire était faite sur 30 humérus de mouton avec montage par 3 broches rectilignes parallèles ou 3 broches incurvées dans

différents plans. Ces montages étaient soumis à des forces de flexion et des forces de rotation au niveau de l'ostéotomie. Les résultats montraient qu'en flexion les broches rectilignes étaient plus rigides que les broches incurvées ($p < 0,001$) et qu'en torsion la fixation avec des broches incurvées était plus rigide que celles avec des broches rectilignes ($p < 0,001$). Une combinaison des 2 types de fixation paraît intéressante.

Introduction

The anatomy of the glenohumeral joint is complex and controls shoulder movement. Therefore, reconstitution of the joint should be considered after a fracture [9, 10]. A fracture below the head of the humerus with considerable displacement is prone to delayed disturbance in shoulder joint function, subsequent to healing [2, 5, 8, 11, 12]. Closed reduction and percutaneous fixation with pins minimise damage to soft tissues and decrease the potential for morbidity [1, 3, 4, 7]. It is common to treat fractures of the surgical neck of the humerus (a two-part fracture, according to the Neer classification) with minimally invasive procedures, such as closed reduction and percutaneous internal fixation with pins [6]. This method minimises the risk of avascular necrosis of the head of the humerus, minimises scarring, and increases the range of postoperative joint motion.

This fixation can be carried out using several methods. To the best of our knowledge, the mechanical rigidity after fixation by contoured pins has not been investigated. In common pin fixation, straight pins are inserted into the lateral aspect of the humerus shaft, towards the humeral head. In this study, the possibility of inserting contoured pins at the same point but dispersing them at different

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planes over the fracture site was examined. It was expected that the pins would increase support in the bone and decrease the risk of injury to the cartilaginous face of the humeral head.

The objective of the study was to analyse the mechanical properties of different types of fixation: conventional fixation by straight pins compared with contoured pins for surgical neck fractures, Neer type 2 [2]. Different configurations were tested by applying direct bending and rotational forces to the fractures subsequent to fixation.

Materials and methods

Type of study Comparative study of two groups: fixation by straight pins (group 1) and fixation by contoured pins (group 2).

Study materials For the study, 30 humerus bones from sheep matched for age and size were used. Bones were stored frozen and slow thawed in a basin of water as required.

Variables The constant variable was the sheep humerus, matched for shape and size, taken from the same side of the sheep. The independent variable was the fixation method (straight vs contoured pins), and the dependent variable was the rigidity of the fixation (R).

Instrumentation Uniform No. 3 Kirschner pins, 2 mm in diameter, were used. Loads were applied using a loading machine (Instron, model 4502, Buckinghamshire, UK).

Mechanical properties The mechanical load producing displacement of the humerus by bending or rotation was obtained in conjunction with the crosshead movement of the machine during loading. For each experiment, the rigidity of the fixation was calculated as the slope of the load as a function of displacement.

Course of the study Contoured pins were obtained by bending straight pins on a mold to produce constant curvature. Fractures were produced in the surgical neck region using an electric saw. The bones were divided into two equal groups of 15 bones each.

Each bone was marked at a constant distance, 7 cm from the greater tuberosity of the humerus, and the pins were inserted at that level (Fig. 1).

In the first group, fixation of each specimen was performed using three straight Kirschner pins, drilled the whole way across the fracture site into the humeral head.

In the second group, in each specimen, three contoured Kirschner pins were introduced through a starting hole drilled into the cortex and then hammered across the fracture site into the humeral head.

Each bone was then embedded in a plastic jar filled with liquid polyethylene and allowed to set. A screw, previously attached to the base of the jar, served as a means of attachment to the loading machine. After setting, mechanical analysis was carried out.

Each bone was tested for bending and torsion using specially designed jigs (Fig. 2). For bending, the bone was connected so that its long axis was perpendicular to the crosshead of the loading machine. The load was applied vertically to the longitudinal bone axis at the head of the

Fig. 1 Bones with **a** contoured pins and **b** straight pins. The loading rod used for torsional loading is also depicted

Fig. 2 **a** Bending test. *White arrow indicates direction of the applied load.* **b** Torsion test. *White arrow indicates direction of the applied load*

humerus through a small compressive plate. For torsional loading, a Shantz pin was inserted into the head of the humerus. The bone was rotated and placed parallel to the crosshead of the loading machine, where the Shantz pin was oriented vertically to the long bone axis. While compressive loads were applied on the distal part of the Shantz pin, torsion occurred at the fracture area.

Load vs deflection data were automatically obtained (Material Testing, Instron, Buckinghamshire, UK) while loading the bones. Load vs displacement showed a linear behavior. Therefore, the rigidity of the fixation was determined by calculating the slope of the linear curve in each loading case (Fig. 3).

Statistics

The study was conducted in collaboration with a statistician. Sample size was determined on the basis of the pilot study using 12 bones, in which 6 were fixed with straight pins and 6 with contoured pins. Rigidity was tested in bending and torsion. It was decided that a difference of at

least 20% in rigidity between the two fixation techniques was required to consider differences between fixations. It was determined that a sample size of 13 bones for each technique would produce 5% statistical significance, with 80% reliability.

Upon completion of data collection and rigidity calculations, the rigidity values for each technique showed normal distribution. Mean and standard deviation of the rigidity values for each group were calculated. An independent *t*-test was performed. A difference of $p < 0.05$ was considered statistically significant. Pearson's correlation was applied to verify whether there was a correlation between rigidity in bending and torsion loading for the same fixation.

Results

Mean rigidity values and standard deviations of the results are shown in Table 1. The independent *t*-test showed a significant difference ($p < 0.001$) between the two fixation groups. Greater rigidity (by 31%) was shown in the fixation

Fig. 3 Characteristic force displacement diagrams obtained during loading. **a** Bending loading. **b** Torsion loading. Rigidity of fixation was calculated as the slope of each curve

Table 1 Mean rigidity and standard deviations (SD) of fixation with straight and contoured pins in N/mm, subject to bending or torsional loadings

Loading type	Pin type	
	Straight	Contoured
Bending	9.36 (0.89) ^a	7.13 (1.23) ^b
Torsional	8.65 (0.80) ^c	10.51 (0.77) ^d

^{a,b,c,d} Significant difference between values having different letters
 $p < 0.001$

group using straight pins compared with contoured pins when subjected to bending load. However, when subjected to torsional loading, the group with contoured pins showed greater rigidity (by 21%) compared with straight pins.

There was no correlation between rigidity under bending or torsional stress in the same bone specimen. This means that a bone which was more resistant to a bending load did not show greater resistance under torsional load, and vice versa.

Discussion

The use of pins is a common mode of fixation for surgical fractures of the humerus neck. This fixation is temporary until initial bone healing occurs, usually within 3–6 weeks. During this time, the pins sustain stresses developed due to arm movement. After initial healing, pins are retrieved, and fixation relies on the natural strength of the bone, which increases over time.

Clinically, pins are inserted from the lateral aspect of the humeral shaft towards the head of the humerus. In our study, two fixation methods were examined, straight vs contoured pins. The contoured pins were inserted in the same manner as the straight pins but distributed in different directions. Thus, the pins dispersed through different points in the fracture cross section. The hypothesis was that contoured pins would increase the mechanical stability compared to the fixation by straight pins.

Fractures produced in the bones by osteotomy were similar. Bones were nearly identical in size, so that the difference in points of crossing the fracture was clearly visible. It was believed that this difference was the source of the observed difference in the results.

The location of the straight pins within the fixation site was concentrated in the medial region of the fracture away

Fig. 4 **a** Straight pins concentrated in a single medial area of the fracture far from the central axis of the bone. **a1** X-ray, **a2** cross section at the fracture site. **b** Contoured pins scattered over the surface of the fracture, with Shanz pin inserted to test rotation. **b1** and **b2** X-rays, **b3** cross section at the fracture site

from the central bone axis (see Fig. 4). Conversely, in bones where contoured pins were used for fixation, pins appeared at three different locations in the circumference of the fracture and at different distances from the central bone axis (see Fig. 4).

Bones fixed by straight pins showed 31% higher rigidity compared to contoured pins when bending was applied. This means that deformations at the fixation were smaller in bending using straight pins. However, the resistance to torsion (rigidity) of the bones with contoured pins was 21% higher compared to straight pins. Similarly, with contoured pins the displacements at the fracture area were smaller when equal torsion loads were applied. This was due to the distribution morphology of the contoured pins at the circumference of the fracture cross section.

When bending loads were applied, the concentration of the pins in one location, as with straight pins, increased the stiffness of the fracture. However, this pin configuration did not increase the stiffness in torsion. To increase the stiffness of a plane during bending, the moment of inertia should be increased and material that can resist tension or compression should be away from the central bone axis. This occurs when all pins are concentrated at one zone, away from the central bone axis. On the other hand, contoured pins resist the sliding between the two parts of the fracture better, since they are spread at different locations in the fracture plane.

The moment of inertia and the polar moment of inertia provide the theoretical explanation for the biomechanical behaviour. The moment of inertia characterises the resistance of a beam to bend. The polar moment of inertia is a measure that characterises the ability of a beam to resist torsion. In this study, the humerus behaved like a beam and the pins were the only structure preventing movement at the fracture site. The moment of inertia for bending was higher for straight pins compared to contoured pins. On the other hand, when torsion was applied, the polar moment of inertia was higher when contoured pins were used.

No correlation was found between the rigidity of a specific type of fixation in response to bending and rotational loads in a single bone specimen. Therefore, it was concluded that the rigidity of fixation subjected to bending or to rotational loads depended only on the type of fixation and not on the bone itself.

Conclusion

In this biomechanical study, fixation of surgical neck fracture of the humerus using three conventional straight pins has been shown to be more resistant to bending forces than contoured pins. In contrast, the use of three contoured pins is more resistant to torsion forces.

In the clinical setting both torsional and bending forces predispose to nonunion and malunion of surgical neck fractures of the humerus, and need to be controlled. The standard treatment postoperatively after fixation of humeral surgical neck fractures is immobilisation of the arm in a sling. The main deforming forces remaining are the deltoid muscle moving the fracture into valgus (bending) and the pectoralis major moving the fracture rotationally.

A similar study, using a combination of the two methods of fixation should now be tested in a clinical setting. This would serve to reinforce the results of the present study.

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