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Virtual morphological comparison of three intramedullary nailing systems for the treatment of proximal humeral fractures

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ABSTRACT

Proximal humerus fractures treated with intramedullary nails show good results. However, the correct anatomical reconstruction of four-part fractures is demanding especially when using intramedullary nails. We therefore compared different intramedullary nail designs for the proximal humerus in a virtual morphological manner. Three commercially available nailing systems where virtually implanted in virtually generated reproducible four-part fractures of 25 digitised humeri. The objective of this study was to quantify and characterise the anatomical position of the proximal screws in the most vulnerable case of a four-part fracture.

Taking into account a minimum distance of 5 mm between the screw head and the fracture line, osteosynthesis was possible in 54 out of 75 cases. Difficulties placing the proximal screws could be observed at the localisation of the lower lesser tubercle or/and at the sulcus intertubercularis. This morphological analysis could be the basis for choosing the most sufficient implant intra operatively or even improving the nail design.

Introduction

About 4% of all fractures in the human body involve the humeral head with severe fractures patterns often seen in the elderly population [1,2]. Non-displaced or only slightly displaced fractures typically are treated non-operatively [3]. There is a certain consensus to treat displaced four-part fractures associated with a high degree of comminution (involving a split head), with primary hemiarthroplasty [3–5]. However, the recommendations for the treatment of displaced three or four-part fractures remain controversial. Recently, there has been a trend to treat proximal humeral fractures with angular stable systems such as plates and intramedullary nails [6–11]. In addition to the treatment with locking plate systems several types of antegrade interlocking nails with uniplanar or multiplanar interlocking modes are currently reported to provide effective means for stabilising proximal humeral fractures [12–17]. According to the manufacturer's instructions, two to four-part fractures may be treated with intramedullary implants. Several recent studies examining the outcome after intramedullary nailing [14,18,19] noted indications including treatment of displaced two and three-part fractures [14,19]. However, four-part fractures were also treated with the intramedullary implants and yielded relatively good results [14,18,19]. Shortcomings of intramedullary nailing include cutting out of the proximal screws and difficulties in a secure fixation of the bone fragments [14,18,19].

For this reason, we examined the nail design morphologically with a focus on screw configuration, i.e. arrangement, position and orientation of the proximal screws, using a new computer based imaging method. We especially focused on how the osteosynthesis is influenced by the anatomical variance, which can be seen in the European population. We used radiographic landmarks for evaluating the anatomical variance, which can also be seen on images taken preoperatively. This could lead to a better appraisal of operative results. Overall, we compared commercially available intramedullary nail systems used for multi-part proximal humerus fractures. Cadaveric humeri corresponding to the

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normal distribution in the European population [20] were used to create a virtual model for implant evaluation. Proceeding in that order, it was possible to acquire implantation data for all three nails in all cadaveric specimens.

Materials and methods

In total 25 fresh frozen cadaver humeri (43–88 years, mean age: 65 years, 16 male, 9 female) were digitised using computer tomography (Cardiac Sensation, Siemens, Erlangen, Germany, 120 kV, 200 mAs, layer thickness of 1 mm) and then reconstructed in 3D using a program specifically developed for medical morphological analyses (Amira, Mercury Computer Systems GmbH, Berlin, Germany). In order to classify the cadaveric specimens anatomically, the software was used to measure the following anatomical landmarks:

1. Diameter of the anatomical neck
2. Diameter of the humeral head
3. Diameter of the shaft

Three intramedullary nails currently available for the treatment of proximal humeral fractures, Targon-PHN (left and right version), T2-PHN (left and right version, bend setup) and TriGen-PHN (unilateral setup), were digitised with the help of a CAD system (Catia V5 R14, Dassault Systems, Suresnes Cedex, France). For clarity reasons, the screws were replaced by short bolts allowing analysis of the proximal screw orientations (see Fig. 1). The Amira program was used to simulate a virtual four-part fracture in the humeri using the four-part fracture according to Codman [21] as a basic model and modifying it according to Resch [3]: The fracture line between the two tubercles does not run in the intertubercular groove, but about 5 mm more laterally. The resulting four fragments are the same as described by Neer [22]: a lesser tubercle fragment, a greater tubercle fragment, the remaining shaft the humeral head with an intact anatomical neck and a fracture at the surgical neck (see Fig. 1).

The nails were virtually implanted according to the manufacturers' instructions and recommendations published in recent specialist literature [19,23]. The nail was inserted at the most cranial point of the humeral head along the diaphyseal axis so that the proximal end of the nail came to lie in the subchondral area of the humeral head directly beneath the surface [23]. In that way, the nail did not project from the bone and potential subacromial impingement [19] was avoided. The nail was rotated to optimise the screws' position in the fragments, i.e. to provide them with a maximum distance from the fragment edge (see Fig. 1). A total of 75 implantations in 25 humeri were conducted in this manner.

After the implantation, the position of the implant was evaluated based on selected distances between the fracture lines

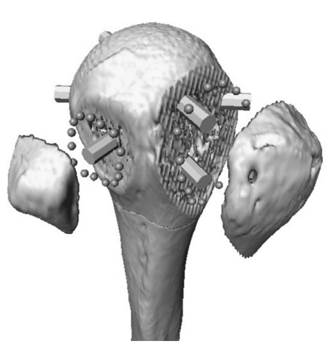

Fig. 1. Four-part fracture and implanted nail (Targon-PHN, Aesculap) with safety margins.

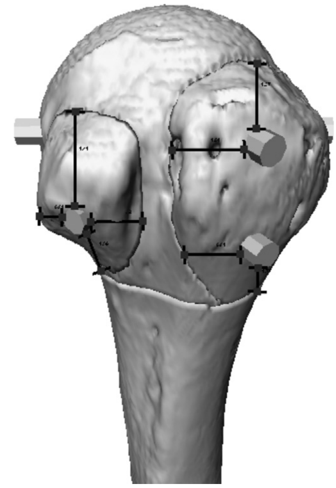

Fig. 2. Measurements from the proximal screws (Targon-PHN) to the fracture lines.

and the screws. Distances were measured in 4 directions at each of the tubercles. These were the cranial and caudal direction as well as the medial and lateral on the lesser and the ventral and dorsal direction at the greater tubercle. Current literature considers an implantation to be safe if there is a distance of at least 5 mm between the screw and the fracture line [23]. Therefore a 5 mm band indicated by landmarks (see Fig. 2) was drawn in parallel to the fracture line to visualise this distance.

For the evaluation of the osteosynthesis, implantation success was divided into three categories (see Fig. 3):

Implantation possible (class A): All inserted screws are at a safe distance of at least 5 mm from the fracture line.
Implantation difficult (class B): At least one of the screws is less than 5 mm from a fracture line or the end of a fragment.
Implantation impossible (class C): At least one of the screws lies outside its fragment.

The normal distribution of the available bone collection was tested with the Kolmogorov–Smirnov-Test and verified based on the epidemiological study [20] by Mall et al. The Mann–Whitney test was performed to see if the implantability depended on the size of the humerus. The next step was to find out whether the available data allowed a prediction of implantability as a function of humerus size using logistic regression and the chi-square test. The results were plotted in a graph showing the probability of a successful implantation as a function of the size (see Fig. 4).

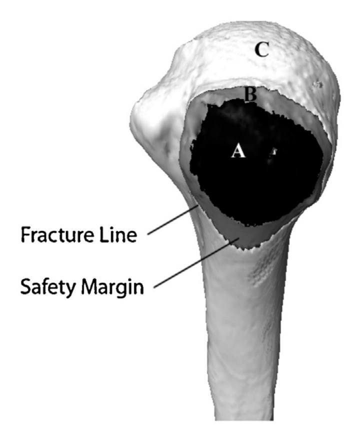

Fig. 3. Evaluation matrix with three categories: implantation possible (A), difficult (B) and impossible (C).