■ TRAUMA

Lack of fifth anchoring point and violation of the insertion of the rotator cuff during antegrade humeral nailing

PITFALLS IN STRAIGHT ANTEGRADE HUMERAL NAILING

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Antegrade nailing of proximal humeral fractures using a straight nail can damage the bony insertion of the supraspinatus tendon and may lead to varus failure of the construct. In order to establish the ideal anatomical landmarks for insertion of the nail and their clinical relevance we analysed CT scans of bilateral proximal humeri in 200 patients (mean age 45.1 years (SD 19.6; 18 to 97) without humeral fractures. The entry point of the nail was defined by the point of intersection of the anteroposterior and lateral vertical axes with the cortex of the humeral head. The critical point was defined as the intersection of the sagittal axis with the medial limit of the insertion of the supraspinatus tendon on the greater tuberosity. The region of interest, i.e. the biggest entry hole that would not encroach on the insertion of the supraspinatus tendon, was calculated setting a 3 mm minimal distance from the critical point. This identified that 38.5% of the humeral heads were categorised as 'critical types', due to morphology in which the predicted offset of the entry point would encroach on the insertion of the supraspinatus tendon that may damage the tendon and reduce the stability of fixation.

We therefore emphasise the need for 'fastidious' pre-operative planning to minimise this risk.

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Fractures of the proximal humerus represent the third most frequent fracture in patients over the age of 65, following fractures of the hip and distal radius.[1] If unstable or displaced, their treatment remains controversial.[2,3] Various surgical techniques, such as minimally invasive fixation with Kirschner (K-) wires or screws, plating, nailing or hemiarthroplasty are available for their management.[3] The choice of the most appropriate technique depends on the experience of the surgeon, with respect to patient's age, bone quality, type of fracture and individual functional expectations. Even with the variety of techniques available, clear evidence-based guidelines are still missing.

Post-operative complication rates as high as 36% have been reported.[4-6] A typical pattern of failure is varus collapse occurring below the humeral head due to lack of medial cortical support as the result of comminution of the calcar or failure of the reconstruction. The risk of failure has shown to increase exponentially in patients with osteoporosis.[7,8] One possible solution to this problem is the creation of an additional proximal bony anchoring point using a straight locking antegrade humeral nail. In three- and four-part fractures, sufficient anchoring in the head fragment seems to be necessary in order to provide initial stability. Ideally, four proximal locking screws guide through the straight nail in different angles, providing four anchoring points within the humeral head (Fig. 1). The nail's tip is then able to anchor the most cranial part of the humeral head (Fig. 1). It is therefore referred to as the 'fifth anchoring point'. However, due to anatomical variations, the insertion point of a straight nail can be placed very laterally and therefore close to the bony insertion of the supraspinatus tendon (SSP). The aim of this study was to assess the potential insertion point for a straight antegrade humeral nail by analysing CT scans of the humeral head.

Materials and Methods

A total of 200 bilateral shoulder CT scans of humeral heads were examined for this study. All CT scans were acquired at our University Department of Radiology. All patients received a CT scan for reasons other than fracture, with the majority acquired for pre-operative quantification of glenoid bone loss in unstable shoulders or for exclusion of bony injury. Due to standardisation at our department, the shoulder CT scans incorporate at least two-thirds of the

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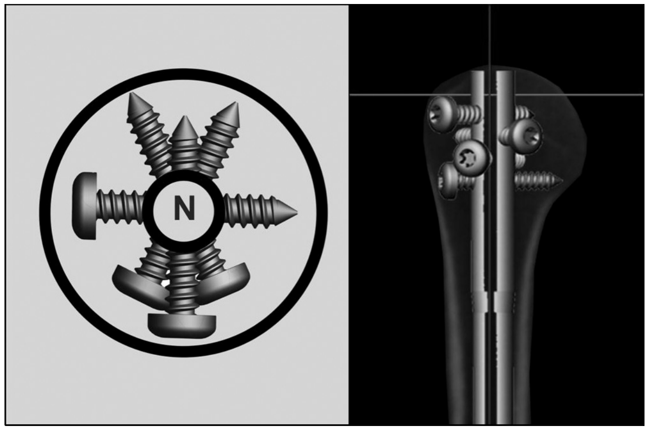

Fig. 1

Drawing of the straight nail's construct configuration and anchoring points. Left drawing: axial view; positioning of the four head screws (N, nail). Right drawing: positioning of four screws and the nail. The screw's tips represent four anchoring points within the humeral head's subchondral bone; the nail's tip represents the 'fifth anchoring point' in the most cranial part of the humeral head.

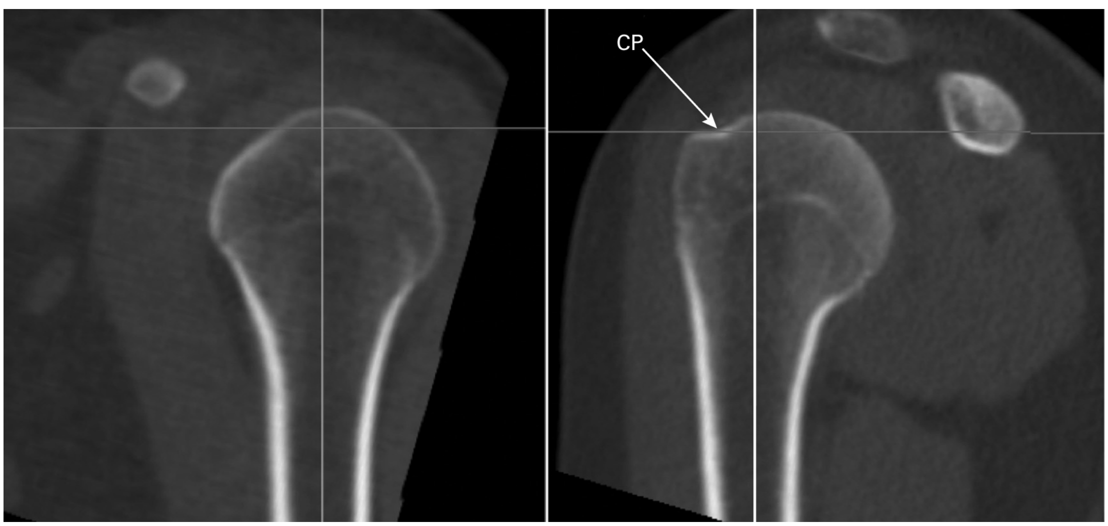

Fig. 2

Reconstructed CT scans of the humeral head/shaft in a true lateral (left image) and anterior/posterior (right image) view. Horizontal line indicates the sagittal axis, vertical lines indicate the axes of the shaft in two planes (CP, critical point).

proximal humeral shaft and one-third of the lateral scapula. The mean age of the patients was 45.1 years (SD 19.6; 18 to 97). The scans were anonymised and reconstructed two-dimensionally (2D) in three perpendicular planes using J-Vision 3.3.16 (Tiani Medgraph, Brunn am Gebirge, Austria). After adjusting the centre of the axis of the humeral shaft using two perpendicular planes, this centre was extrapolated proximally through the humeral head to mark the potential site for the insertion of a straight nail.

The virtual entry point for the nail was adjusted as follows: true anterior/posterior and true lateral adjustment; vertical anatomical axis through the humeral shaft in two planes and adjustment to the axis of the head; sagittal axis through the most medial part of the insertion of the SSP (transition zone) to adjust to the level of the tendon's inception (Fig. 2).

The intersection between this sagittal axis and the cortical border of the humerus was defined as the critical point (CP) (Fig. 2). The region of interest (ROI) was then defined as the largest possible circle in the axial view, centred on the entry point so as not to compromise the CP.

Therefore, the ROI represents the biggest permitted hole in the humeral head for insertion of the nail that would not damage the bony insertion of the SSP (Fig. 3). Hertel et al[12] described the offset of the greater tuberosity to be the distance between the insertion of the innermost fibres of the

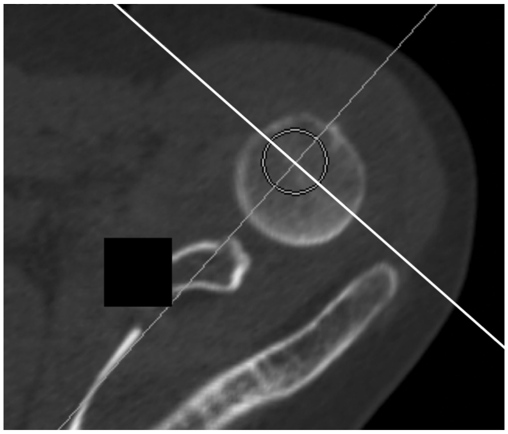

Fig. 3

Reconstructed CT scan of the humeral head/shaft. Axial view at the level of the critical point (CP). Small white central circle indicates the region of interest (ROI). Diameter (d) of the ROI/2 = radius = critical distance (CD).

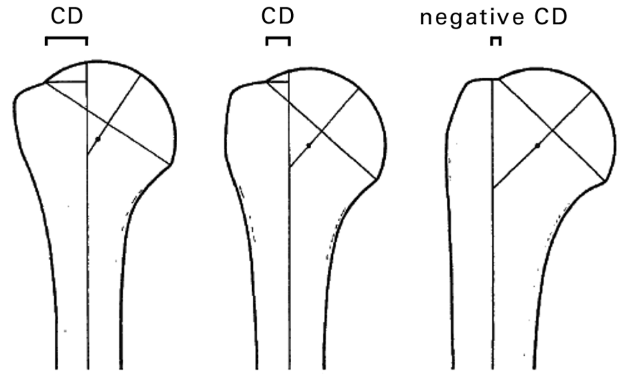

Fig. 4

Different types of offset: high-offset (left image), standard (middle image), and low-offset (right image) morphotypes according to Hertel.[12] CD, critical distance. Reproduced with permission.

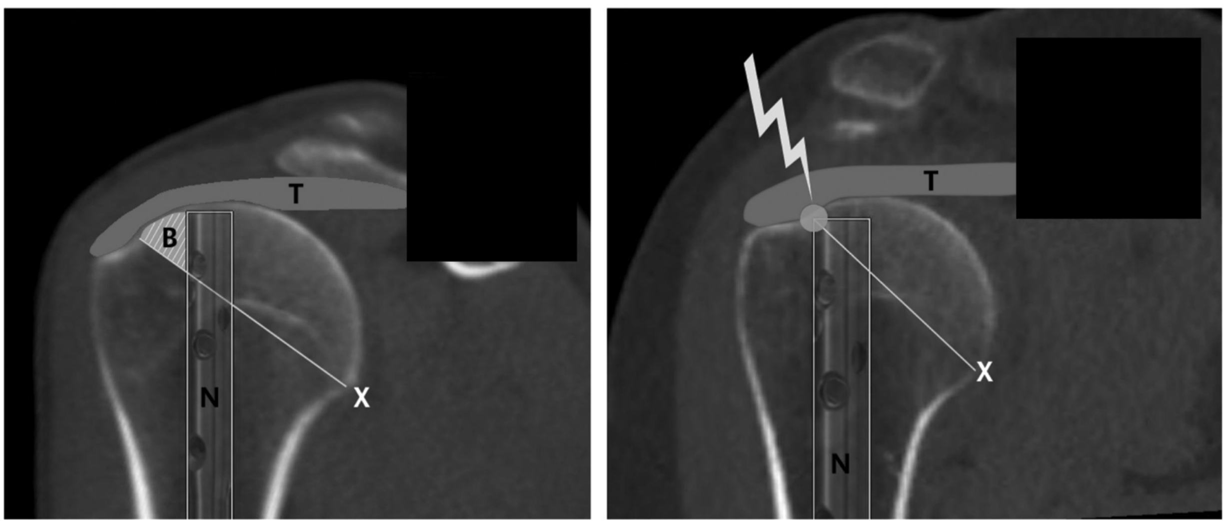

Fig. 5

Reconstructed CT scans of the humeral head/shaft with the assumed position of the straight antegrade nail (N). Nail's diameter is 8 mm in both views. Safe Type (left image): B: bone substance surrounding the nail's tip (fifth anchoring point). Critical Type (right image): small circle indicates the bone substance surrounding the nail's tip and the flash shows the small circle, 'lack' of the fifth anchoring point. White lines leading to the cartilage transition point (X) indicate the onset of the cartilage (T, tendon of supraspinatus).

insertion of the SSP and the axis of the proximal humeral shaft. Accordingly, they described three different anatomical patterns; the standard, the high-offset and the low-offset humerus (Fig. 4). We defined the critical distance (CD) as the distance between the CP and the centre of the circular ROI (Fig. 3). The minimal safety distance was set to 3 mm medially to the CP by means of the lateral limit of the ROI. Thus, the nail may not interfere with the insertion of the SSP but allow for reasonable fixation in the head fragment.

Different designs of straight nails used for reconstructions are available on the market. However, in order to achieve fixation, the tip of the nail should be designed to be thicker than the nail shaft. The diameters range from 9.5 mm to 12.5 mm at the tip to 7 mm to 10 mm at the shaft, with a recommended minimal proximal reaming diameter of 10 mm, depending on the manufacturer. Therefore, the smallest possible radius needed for antegrade nailing procedures in the proximal humerus is 5 mm. In total, a safety distance of at least 8 mm from the CP is required in order to avoid harm to the insertion of the SSP and still allow proper fixation. This led us to differentiate between two types of humeral head: the 'safe type', where the safety distance was not exceeded, and the 'critical type', where it was exceeded (Fig. 5).

Statistical analysis. SPSS Statistics version 20 (IBM, Armonk, New York) and Analyse-it for Microsoft Excel 3.20 (Analyse-it Software, Ltd http://www.analyse-it.com; 2013) were used for the statistical analysis. Metric scaled data are reported as mean with standard deviation and cat-

Table I. Overview of results

	Right humeral head (n = 200)	Left humeral head (n = 200)	Right and left (n = 400)
Mean (SD) critical distance (mm)	8.52 (1.96)	8.49 (1.98)	8.51 (1.97)
Save type (n, %)	127 (*63.5*)	119 (*59.5*)	246 (*61.5*)
Critical type (n, %)	73 (*36.5*)	81 (*40.5*)	154 (*38.5*)

egorical data as absolute frequency. Depending on the distribution form, a paired *t*-test or a Wilcoxon test was used for the analysis of metric scaled data. The distribution form was determined using the Kolmogorov–Smirnov test. The probability level was set at $p < 0.05$. For the assessment of the intra- and inter-observer repeatability, the repeatability coefficient according to Bland and Altman[13] (1.96 times the SD of the differences between the two measurements) was calculated. This coefficient indicates that the difference between repeated measurements is lower than the calculated value in 95% of all cases. Bilateral data of critical distances was used for this purpose.

Results

We observed a mean CD of 8.52 mm (SD 1.96; 4.6 to 12.8) in right and 8.49 mm (SD 1.98; 3.5 to 14.1) in left humeral heads. Differences between left and right humeri within individual patients were not significant. The defined safety distance of 8 mm was exceeded in 154 shoulders (77 patients, 38.5%). Repeatability coefficients were 0.79 for the inter-observer and 1.25 for the intra-observer assessment. The results are summarised in Table I.

Discussion

The data demonstrate that 38.5% (154 of 400) of all humeral heads in a large representative cohort appear to be ‘critical types’. Other authors have also reported a potential risk of damage to the insertion of the SSP and impaired fixation of the nail in humeral heads of this type.[19]

In order to decrease the risk of varus failure, bent antegrade intramedullary nailing has been introduced for the stabilisation of proximal humeral fractures, especially in older patients with osteoporotic bone.[14,15] The recommended insertion point for these designs inevitably violates the footprint of the insertion of the tendon of supraspinatus. Biomechanically, the stability of antegrade humeral nails is at least comparable to plate fixation.[16] Recently, straight antegrade locking nails have been introduced. The crucial difference between the bent and the straight design is their positioning in the humeral head. Straight nails anchor more medially at the apex of the humeral head. To date, there are no studies documenting a significant increase of the strength of fixation when using a straight antegrade nail– an increase that may lead to improved fracture healing. Nevertheless, some authors have measured the local bone mineral density (BMD) within the humeral head. Lill et al[17] found the highest BMD in the most cranial aspects of the medial and dorsal regions of the proximal humerus in all age groups. The lowest BMD and the lowest mechanical rigidity were found in the central parts of the humeral head and at the greater tuberosity.[17] Tingart et al[18] observed that the trabecular BMD of the humeral head had a significant effect on the pullout strength of cancellous screws. The group also found that the medio-dorsal and cranial areas of the humeral head provided the most rigid areas by means of bone density.[18] In order to achieve the most solid fixation, these authors strongly recommend the implant to be placed as far medially and cranially in the humeral head as possible. In addition, due to the nail anchoring the most solid bone of the humeral head, its tip is able to counteract the varus pulling forces of the SSP. Thus, the risk of varus failure can be minimised.[9] The authors therefore believe that straight antegrade humeral nails may engage and stabilise the head fragment to become a ‘fifth anchoring point’. Three-dimensional screw interlocking at the same level as well as closer approximation of the nail to the centre of rotation of the fracture may improve stability.[10] Furthermore, using a minimally-invasive technique, surrounding soft tissues are presumed to be largely protected from damage.[11]

However, in order to ensure the ‘fifth anchoring point’, good bony quality at the tip of the nail is mandatory. If the insertion point is set too far lateral, the bony quality may be weak, potentially leading to inadequate fixation.[19] A frequent criticism of antegrade straight and locked nailing is the violation of the insertion of the SSP.[10] Minimal invasiveness is achieved by a trans-tendinous access. Thus, some authors state that due to the violation of the insertion of the SSP, the functional outcome is lower than following locked plating procedures.[20,21]

Little attention has been focused on the risk of damaging the rotator cuff during the surgical approach. Sharp lengthwise splitting of the SSP does not seem to impair its function.[22] However, violation of the innermost fibres at the level of the tendon’s insertion may interfere with the blood supply at the transition zone.[12,23]

In the present study, the authors described the ideal insertion point for straight nails at the humeral head in respect to the shaft axis after 2D reconstruction. In this work, 38.5% of all humeral heads appeared to be ‘critical types’. Furthermore, the data are based on the smallest designed nail’s diameter available on the market. However, due to anatomical variability and to special fracture situations, nails with thicker tips are needed in some individuals. In such situations, the percentage of ‘critical types’ would further rise. In 2002, Hertel et al[12] anatomically evaluated

200 humeral cadavers and observed that implantation of a straight-stemmed prosthesis that fills the medullary canal of the humerus would have caused damage to the insertion zone of the rotator cuff in 49.5% of the specimens.

There are limitations to the present study. Pre-existing lesions of the rotator cuff may be evident in 23% of the normal population[24] and may limit the functional outcome. The incidence of a complete rotator cuff tear or avulsion in association with proximal humeral fractures varies between 23% and 40% with increasing numbers in older patients.[25-27] For this reason, intramedullary nailing has been primarily recommended for elderly patients.[28] Additionally, the impact of mechanical changes due to straight antegrade humeral nailing procedures on the stability of 'critical humeral heads' is unknown and needs further investigation. Further biomechanical investigations which take into account differences in bone quality as well as the impact of the diameter of the shaft and tip of the nail need to be performed to prove the clinical significance of the 'fifth anchoring point'.

This study leads the authors to believe that straight antegrade locking nail fixation for fractures of the proximal humerus is a favourable option. Nevertheless, an undisturbed function of the rotator cuff is mandatory to provide satisfactory functional results. Furthermore, the rationale of the additional fifth fixing point is only tenable if the tip of the nail can anchor firmly in strong bone.

In terms of CD, we did not find significant differences between left and right humeri within individuals (p = 0.47), and both sides appear to be comparable. It is therefore highly recommended that careful pre-operative planning to assess the anatomical characteristics of the SSP's bony insertion is conducted. Bilateral CT scans should be obtained in order to estimate the anatomical basics. Evaluation of the contralateral humeral head is suitable, as conditions appear to be comparable. The tendinous footprint cannot be certainly protected, if the CD is exceeded. In those patients in whom loss of fixation might be anticipated, alternative forms of fixation should be considered.

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