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ORIGINAL ARTICLE

A new straight proximal humeral nail: a cadaveric study of its anatomical relationships

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Summary

New humeral nailing systems appear constantly in the market, but few anatomical studies assessing the potential risks of neurovascular injury, exist. The aim of this study is to determine the potential risk of neurovascular injury during proximal and distal locking.

An anatomical analysis was carried out in cadavers where a new straight proximal humeral nail had been inserted.

The nail entry point was always located medially to the myotendinous junction of the supraspinatus muscle, therefore affecting only muscle fibres. The nail entry point was surrounded by articular cartilage of the humeral head. The axillary nerve and the posterior humeral circumflex artery were at safe distances (>2cm) from all proximal and distal locking screws. The radial nerve and its accompanying artery, the *profunda brachii* artery, were at risk whenever medial cortex violation happened, as they were located within 1cm of the exit point of the most distal locking screw.

The straight humeral nail analysed in the current study seems to be more secure in relation to the neurovascular injury potential when compared to previously reported ones. Only the incorrect selection of the length of the most distal locking screw may lead to injury of the radial nerve and/or *profunda brachii* artery; therefore, close monitorisation during the insertion of this distal locking screw is recommended.

Keywords: Shoulder – Fractures – Fixation – Neurovascular injury

Introduction

Fractures of the proximal humerus are among the most frequent fractures in the elderly. Classically, proximal humeral nailing has been reserved for two-part Neer fractures and the conventional antegrade approach has been associated with persistent pain and compromised shoulder function. Furthermore, due to the proximity of the axillary nerve, this approach is associated with a potential risk of nerve injury during fixation with proximal interlocking techniques (Karataglis et al, 2011).

Multiloc Proximal Humeral Nail (Synthes; Solothurn, Switzerland) is a new straight nail that theoretically minimizes the damage to the rotator cuff tendon because of its more medial entry point. Additionally, the creation

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of a more medial entry hole results in the upper end of the nail being completely surrounded by osteochondral tissue in the humeral head fragment, providing additional stability to the head fixation screws.

The purpose of this study is to establish the anatomical relationships of this new humeral nail and to determine the potential risk of neurovascular injury during proximal and distal locking.

Material and methods

Four shoulders (3 right, 1 left) from three preserved human cadavers were used. The bodies were donated during life in accordance with current regulations for body donation.

All the upper extremities were intact, and they also contained an intact scapulothoracic joint in order to preserve the normal anatomy. Specimens with an abnormal shoulder anatomy, rotator cuff tears, or previous shoulder surgery were discarded.

The procedure for the insertion of the Multiloc Proximal Humeral Nail was the one recommended by the manufacturer (Synthes, Solothurn, Switzerland). All possible locking screws were inserted to study their anatomical relationships (Fig. 1c).

Once the surgical technique had been performed and in order to establish the anatomical relationships, the anterior part of the deltoid muscle was detached from its insertion in the anterior part of acromion and clavicula, and retracted laterally preserving the anatomical relationships unaltered. Subsequently, dissection of the axillary nerve, the anterior circumflex artery and its ascending branch, the posterior circumflex artery, the tendon of the long head of the *biceps brachii* (LBB) and the radial nerve, was carefully carried out (Figs. 1, 2).

Once all the anatomical details were exposed and in order to minimize inter- and intra-observer variability, three independent investigators measured each of the following distances twice (non-consecutively): (a) Acromion to nail entry point and to each screw; (b) Acromion to axillary nerve and to ascending branch of circumflex artery; (c) Tendon of the long head of the biceps brachii to nail entry point and anterior screw; (d) Entry point to the supraspinatus myotendinous junction; (e) Distal locking screw and its prolongation through the medial humeral cortex to the radial nerve.

All measurements were made with a digital caliper with a precision of a hundredth of a millimeter. When measuring the distance between two structures, the smallest distance was considered.

Once the above mentioned distances had been recorded, the screw's entry points in the deltoid muscle were marked with a pin, the axillary nerve and the posterior circumflex artery fixed with a pin to the deltoid muscle, and finally, the deltoid muscle was completely detached. Then, following the same measur-

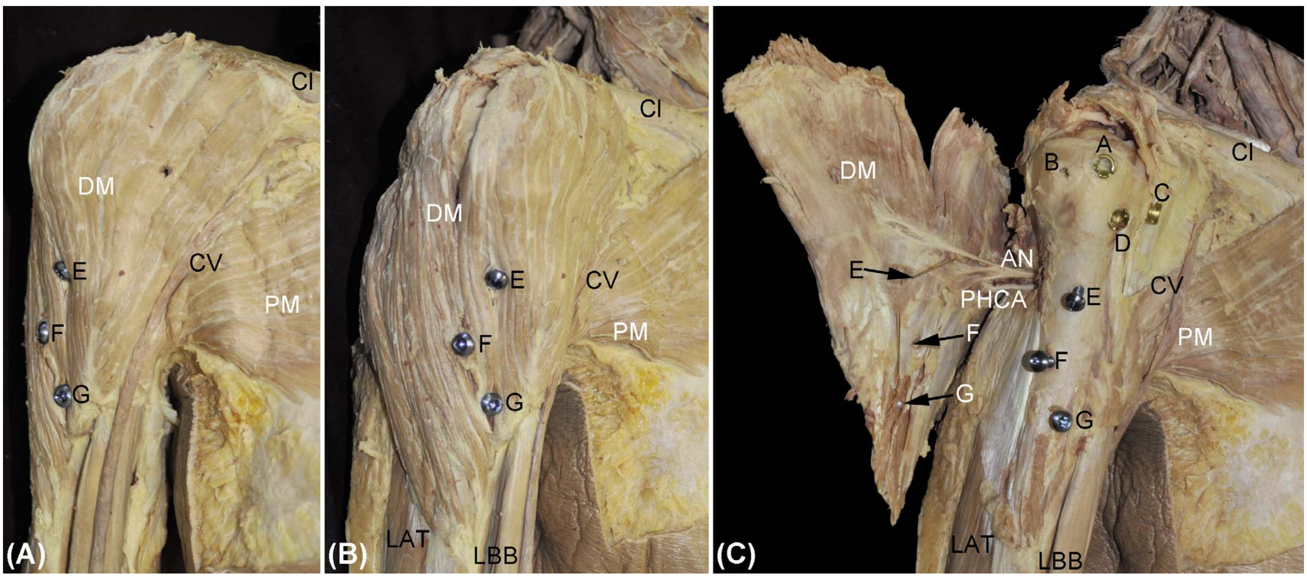

Fig. 1. Anterior views of a right shoulder showing the anatomical relationships of the proximal (A-D) and distal locking (E-G) screws with the cephalic vein (CV), axillary nerve (AN) and posterior humeral circumflex artery (PHCA). Cl: Clavicula, DM: deltoid muscle, PM: *pectoralis major* muscle, LAT: lateral head of triceps brachii muscle, LBB: long head of the biceps brachii muscle.

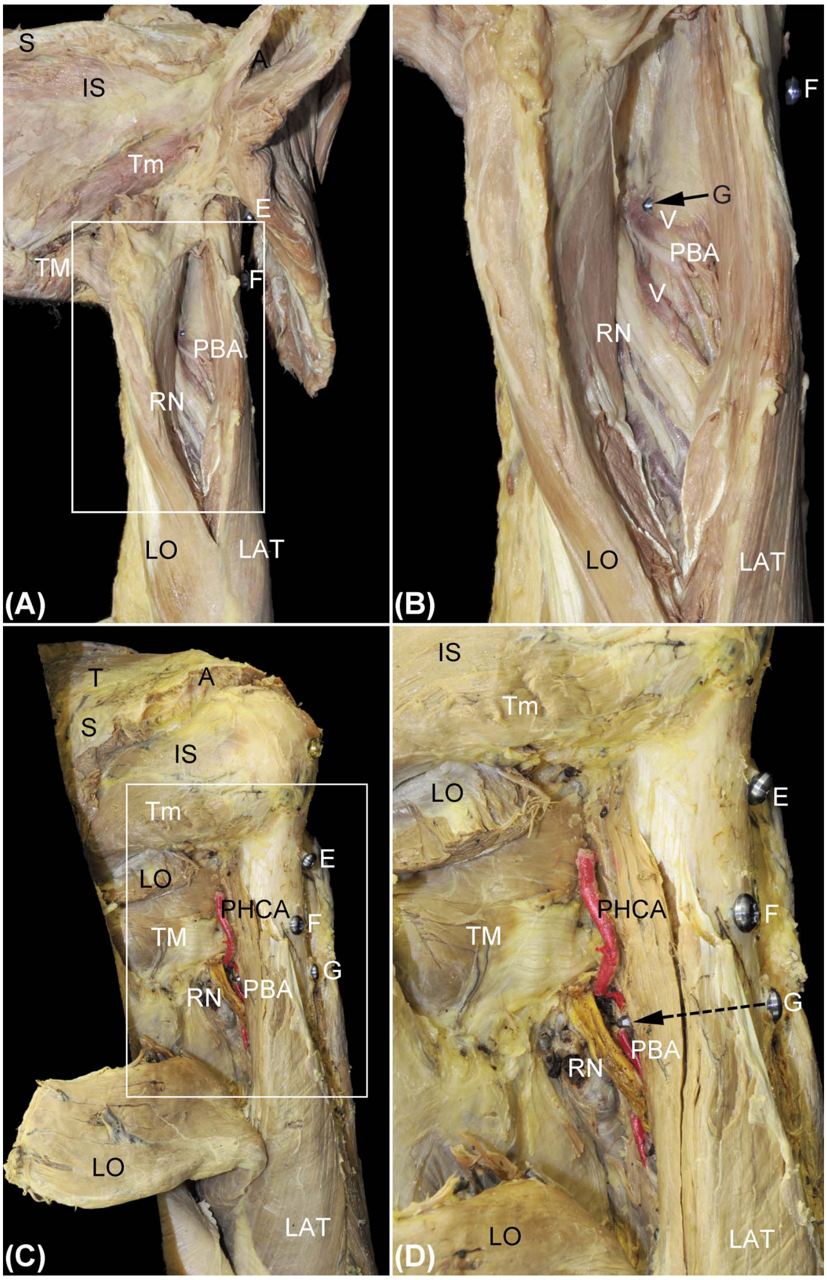

Fig. 2. Posterior view of two different right shoulders showing the relationship between the distal locking screws (E-G) and the radial nerve (RN). (A) Low and (B) high magnification photographs showing the close relationship of the exit point of screw G (arrow) and the radial nerve and *profunda brachii* artery (PBA). (C, D) The long head of triceps brachii muscle (LO) has been cut and displaced medially to allow a better visualisation of the anatomical structures. Note the variant origin of the *profunda brachii* artery (PBA) from the posterior humeral circunflex artery (PHCA), reported to occur in 5% of cases (Lippert and Pabst, 1985). Note also how the exit of screw G (arrow) damaged the PBA and may potentially damage the RN. S: Scapular spine, A: acromion, LAT: lateral head of triceps brachii muscle, T: Trapezius muscle, Tm: Teres minor muscle, TM: Teres major muscle, IS: Infraspinatus muscle, V: vein.

ing protocol as above, the (f) Axillary nerve to every locking screw distance and (g) Circumflex artery to every locking screw distance, were measured.

Results

All locking screws crossed the deltoid muscle fibres lateral to the delto-pectoral groove (Fig. 1A, B).

The anatomic position of the axillary nerve varied in each human specimen. The average distance from the lateral edge of the acromion to the axillary nerve was 58.65 mm (range 30.70-74.15 mm); the measured distance to the posterior humeral circumflex artery was 61.66 (range 33.78-75.70 mm).

All screws (A to G) were at a safe distance from the axillary nerve in all studied shoulders (Fig. 1C). The screws closest to the axillary nerve were D and E; the minimum distance between screw D and the axillary nerve was 31.99 mm, and 23.30 mm between the nerve and screw E, leaving at least a two-centimeter security margin in all cases (Table 1).

Regarding the posterior circumflex artery, all screws were at a safe distance, screw E being the closest one with a minimum distance of 20.16 mm (Table 1).

Table 1. Details of measurements between the acromion, the most relevant locking screws, the axillary nerve, and the posterior humeral circumflex artery. Distances are given in mm. Mean (range).

	Acromion	Axillary nerve	Circumflex artery
Acromion		58.65 (30.70-74.15)	61.66 (33.78-75.70)
C screw	47.70 (39.87-58.01)	85.61 (61.02-121.70)	88.50(61.02-132.96)
D screw	45.25 (40.26-52.28)	47.16 (31.99-64.25)	
E screw	69.80 (64.01-77.57)	39.71 (23.30-69.58)	37.52 (20.16-48.61)

The long head of the *biceps brachii* muscle may be at risk by the insertion of the nail and also the anteroposterior screw (screw C; Fig. 1C). The smallest distance between the anteroposterior screw C and the tendon was 1.52 mm (range 1.52-19.25 mm; mean 9.57mm), and the smallest distance between the nail entry point and the tendon was 1.94 mm (range 1.94-9.05 mm; mean 6.56 mm).

Due to the importance of ascertaining the part of the supraspinatus muscle or tendon that is affected by humeral nailing systems, we measured the distance between the upper entry point and the myotendinous junction of the supraspinatus muscle. The nail entered the supraspinatus muscle mass in all cases, being the myotendinous junction located an average of 4.5 mm (range 2.21-7.30 mm) lateral to the entry point.

The distance between the greater tuberosity (end up of articular cartilage) and the entry point averaged 16.35 mm (range 14.28-19.26 mm), the nail entry point being always surrounded by articular cartilage.

Finally, we analyzed the distances between the exit of the distal locking screws, the radial nerve and the *profunda brachii* artery (Fig. 2A, B). The most distal locking screw (G) was the one that could most likely damage the radial nerve or the accompanying artery as, in all cases, it was within a distance of less than 1 cm (range 0.15-8.38 mm; mean 4.52mm). In one case where the *profunda brachii* artery originated as a variation from the posterior humeral circumflex artery, it was pierced by the tip of the screw (Fig. 2C, D).

Discussion

The surgical anatomy of the shoulder is still one of the workhorses for the orthopedic surgeon. Fractures, dislocations or even simple surgery related to this complex anatomical region endanger structures that can occasionally lead to important complications and limiting injuries for daily life activities (Boardman and Cofield, 1999).

There is close consensus in treating two part displaced humeral fractures with intramedullary nailing However, the emergence of new intramedullary nails with increased proximal locking options has extended this indication to fractures with three and even four fragments, although the results in these latter fractures are more inconsistent (Nolan et al., 2010).

The locking screws of most commercial implants endanger the axillary nerve (Prince et al, 2004). When the axillary nerve, carrying fibres from C5 and C6 exits through the quadrilateral space it divides into anterior and posterior branch (Apaydin et al, 2010). Although the pattern of division is variable (Duparc et al., 1997; Uz et al., 2007), the most frequent pattern should be well known because of its clinical implications. The anterior branch surrounds the surgical head of the humerus while the posterior branch supplies the teres minor, the posterior part of the deltoid and ends in the lateral cutaneous nerve of the arm (Apaydin et al., 2010). The anterior branch is clinically the most relevant for the shoulder surgeon and previous anatomical studies have established the distance between the acromion and the axillary nerve; so, in our study, the distance between the lateral aspect of the acromion and the axillary nerve was on average 5.8cm, which is consistent with other anatomical studies (Burkhead et al., 1992; Kamineni et al, 2004; Cetik et al., 2006; Apaydin et al., 2010).

The risk exists both with flexible humeral nails (Albritton et al., 2003) and with straight nails (Riemer and D'Ambrosia, 1992; Prince et al., 2004). However, our cadaveric study with Multiloc Humeral Nail (Synthes; Solothurn, Switzerland) shows that with this new implant the closest distance of any of the screws to the axillary nerve was 2.3 cm. Although a morphometric study showed important differences in humeral morphology (Akpinar et al., 2003), and although body size may affect the distance between acromion and axillary nerve, the fact that, independently of body size, there was at least a 2 cm gap between any screw and the axillary nerve entitles us to affirm that, at least in relation to this nerve, this new system is safe. Although we believe that a 2 cm distance is safe enough, taking into consideration potential appearance of anatomical variations, we recommend sharp dissection of deltoid fibers and the use of protection sleeve before inserting proximal locking screws.

Apart from the axillary nerve, other vascular structures have been related to locking system. Classical studies of humeral head vascularization showed perfusion to be dependent on the ascending branch of the anterior humeral circumflex artery which consistently lies within the biccipital groove (Gerber et al., 1990). However, it has been recently reported that the contribution of the posterior humeral circumflex artery to humeral head blood supply is more significant than previously thought (Hettrich et al., 2010). The highest risk of injury is theoretically in relation to the anteroposterior locking screws (Nijs et al., 2008), which is confirmed in the current work where the anterior locking screws were very close to the long head of the *biceps brachii* muscle and hence to the biccipital groove where the anterior artery lies. However, taking into consideration that the smallest distance of any of the screws to the posterior humeral circumflex artery is at least 2.01 cm, it makes its injury potential minimal and avoidable, and no complications in relation with avascular necrosis should be predicted to occur.

Another important consideration is the entry point; passing through the rotator cuff leads to important complications such as persistent residual pain or functional limitation (Nolan et al., 2011). Furthermore, there is a critical hypovascular zone in the distal 15 mm of both the supraspinatus and infraspinatus muscles (Brooks et al., 1992) and its damage is believed to be one of the factors responsible for poor shoulder function after anterograde intramedullary.

When using flexible curved nails this hypovascularized zone is often pierced (Riemer et al., 1993), and it has been suggested that the nail be introduced through the rotator interval to avoid damage to this zone (Park et al., 2008). In contrast, although we used the same approach, with the use of the new straight nail this zone was avoided as the entry point was located more medially (at an average distance of 16mm from the insertion of the supraspinatus), and always medial to the myotendinous junction in an area of rich blood supply.

Finally, the current study revealed the importance in selecting the right length of the most distal locking screw. While using an especially long screw in order to be able to study the anatomical relationships of the screw's exit point, an intimate relationship with the radial nerve and/or its accompanying artery, the *profunda brachii* artery, was revealed. Racial differences of the course of the radial nerve have been reported (Chou et al., 2008), but in all our cases (Caucasians), the exit point was within 1cm of the radial nerve or the artery, making them highly susceptible to injury. In one of the cases, the radial nerve was in direct contact with the tip of the screw, while in another case the tip of the screw had pierced the *profunda brachii* artery, which originated as a variation from the posterior humeral circumflex artery (reported to occur in 5% of cases) (Lippert and Pabst, 1985). The fact that the *profunda brachii* artery forms a close circuit with the radial recurrent artery, may potentially minimize the blood supply loss if injury occurs, but could lead to clinical complications such as profuse bleeding or important hematoma formation. Although we consider the radial nerve and the *profunda brachii* artery to be at risk and therefore recommend to carefully select the length of the screw and closely monitor its insertion, the loss of viscoelastic properties of the tissues as the specimens where formalin-fixed, should not be overlooked.

Although our study has some limitations as for example the sample size studied or the use of formalin-preserved specimens, antegrade humeral nailing with Multiloc Humeral Nail (Synthes; Solothurn, Switzerland) and its multiple locking options appears to be a safe procedure with regard to potential injury to neurovascular structures if the correct screw length are selected and their insertion is closely monitored. Furthermore, less disruption is caused to the supraspinatus muscle while introducing the nail.

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