Acta Med. Okayama, 2017
Vol. 71, No. 6, pp. 525-529

Acta Medica Okayama
http://escholarship.lib.okayama-u.ac.jp/amo/

Original Article

Relationship between the Axillary Nerve and Accompanying Vessels and Proximal Humeral Locking Plates in Japanese: An MRI Study

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We investigated the anatomical features of the axillary nerve and its accompanying vessels with respect to the lateral wall of the greater tuberosity, focusing on the relationship between the neurovascular bundle and the proximal humeral locking plates. Magnetic resonance images of 30 Japanese patients' shoulders were examined. Oblique sagittal images across the greater tuberosity and the neurovascular bundle, which contain the axillary nerve and posterior circumflex humeral artery and vein, were obtained. The distance between the superior aspect of the greater tuberosity and the superior and inferior borders of the neurovascular bundles was measured at the anterior, middle, and posterior edges of the greater tuberosity. The neurovascular bundle was 28.5-36.7 mm, 32.6-41.3 mm, and 38.1-47.5 mm distal to the superior aspect of the greater tuberosity at the anterior, middle, and posterior edges, respectively. We evaluated the relationship between the neurovascular bundle and 3 different locking plates, which were placed at the lateral aspect of the greater tuberosity. Only 3 or four locking screws at the most proximal part could be safely inserted without axillary nerve interference.

Key words: proximal humeral fracture, locking plate, axillary nerve, posterior circumflex humeral artery, shoulder

Minimally invasive plate osteosynthesis (MIPO) is widely used as a good treatment option for fractures. The proximal humeral fracture is treated using MIPO via the anterolateral deltoid-splitting approach, and good clinical results have been reported [1-6]. However, this approach is occasionally challenging because of an anatomical feature in which the axillary nerve overlies the locking plate [3,4]. The axillary nerve (C5 and C6) branches from the posterior cord of the brachial plexus and passes through the quadrilateral space in the anteroposterior direction. The axillary nerve splits into 2 branches (the anterior and posterior branches), and the anterior branch travels around the surgical neck of the humerus and innervates the anterior segment of the deltoid [7]. Thus, the anterior branch of the axillary nerve seems to be in contact with the locking plate after surgical treatment. Transient axillary nerve paralysis was observed in several clinical studies investigating the MIPO technique [4].

The anatomical relationship between the axillary nerve and the screws of the proximal humeral locking plates has been evaluated in some cadaveric studies [8-11]. Smith *et al.* reported that the holes near the middle of the locking plate intersected the course of the axillary nerve and were unsafe for screw insertion [8]. Cetik *et al.* showed the safe zone for deltoid-splitting incision to avoid axillary nerve injury [11]. Stecco *et al.* also showed the safe zone during the transdeltoid approach and indicated that the 2 distal screws of the proximal humeral internal locking system (PHILOS) plate had a risk of nerve injury during insertion [12].

These reports showed the importance of avoiding axillary nerve injury during the deltoid-splitting

Received April 6, 2017; accepted July 13, 2017.
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Conflict of Interest Disclosures: No potential conflict of interest relevant to this article was reported.

approach for a proximal humeral fracture; however, they did not take into account racial differences in body size. The Japanese, especially the elderly, are generally smaller than Africans, Americans, and Caucasians of the same age. In a small body, the locking plates are relatively larger compared to the humerus, and the course of the axillary nerve over the locking plates should be different. There are no data about axillary nerve anatomy in the Japanese population. We conducted the present study to clarify the anatomical features of the axillary nerve with respect to the lateral wall of the greater tuberosity and to evaluate the relationship between the neurovascular bundle and the proximal humeral locking plates in a Japanese population.

Patients and Methods

Patients who visited our hospital with shoulder problems and who were without rotator cuff tears or superior migration of the humeral head on magnetic resonance (MR) images were included in this study, which was approved by the institutional review board at Onomichi Municipal Hospital. All procedures were carried out with the adequate understanding and written consent of each subject. Patients in whom we were unable to obtain suitable MR images were excluded. There were 30 Japanese patients (18 males and 12 females), and their mean age was 57 years (range, 24-82 years). Their mean height and weight were 162.5 cm (range, 151-175 cm) and 61.9 kg (range, 42-123 kg), respectively. MR imaging was performed for 30 shoulders of 30 patients using a Philips Intera 1.5T (Philips Electronics Japan, Tokyo, Japan). Twenty-one patients were diagnosed with periarthritis of the shoulder including subacromial bursitis or impingements, cuff tendonitis, and frozen shoulder. One patient had a loose shoulder, and another patient had a throwing shoulder injury. Seven patients had no evidence of shoulder problems.

We planned to assess the axillary nerve anatomy on MR images; however, the axillary nerve was not clearly identifiable because the axillary nerve ran with its accompanying blood vessels that branched from the posterior circumflex humeral artery and vein. The nerve and the blood vessels passed around the lateral wall of the greater tuberosity from the posteroinferior to the anterosuperior direction. Each cord of the nerve and vessels was unidentifiable because they were narrow bands and had similar T2 values. The vessels, especially the branches of the posterior circumflex humeral artery, are also important and should be avoided to prevent iatrogenic injury during the deltoid-splitting approach. We therefore treated these nerves and vessels as a neurovascular bundle and evaluated the anatomical features of this neurovascular bundle including the axillary nerve and the posterior circumflex humeral artery and vein.

Evaluation of the passage of the neurovascular bundle. We evaluated the MR images in the oblique sagittal image view, across the greater tuberosity and the neurovascular bundle (which contains the axillary nerve and the posterior circumflex humeral artery and vein) (Fig. 1). The neurovascular bundle was identified as having flow voids in the oblique-coronal images and continuity to the axillary nerve and artery in the serial MR images.

A reference line passing through the superior aspect of the greater tuberosity and perpendicular to the long axis of the humeral shaft was drawn on the MR image using Synapse 4.1.0 software (Fujifilm Medical USA, Stamford, CT). The distance between the reference line and the superior and inferior borders of the neurovascular bundles was measured at the anterior edge, middle, and posterior edge of the greater tuberosity (Fig. 2). Thus, the distance between the reference line and the anterosuperior, anteroinferior, middle-superior, middle-inferior, posterosuperior, and posteroinferior borders of the neurovascular bundle was evaluated. The measurement was done twice by a single investigator (YS), and the average was used in the analysis.

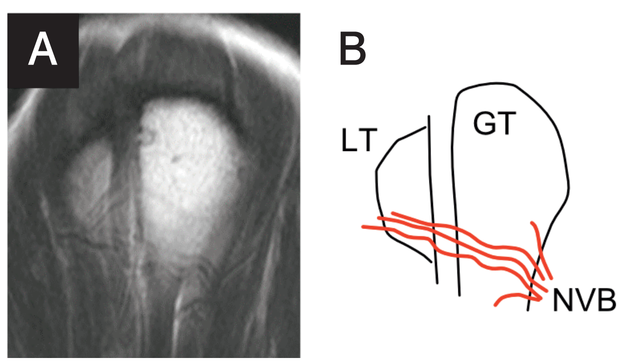

Fig. 1 A, An oblique sagittal MR image showing the greater tuberosity and the neurovascular bundle; B, The schema of the MR image. NVB, neurovascular bundle; LT, lesser tuberosity; GT, greater tuberosity.

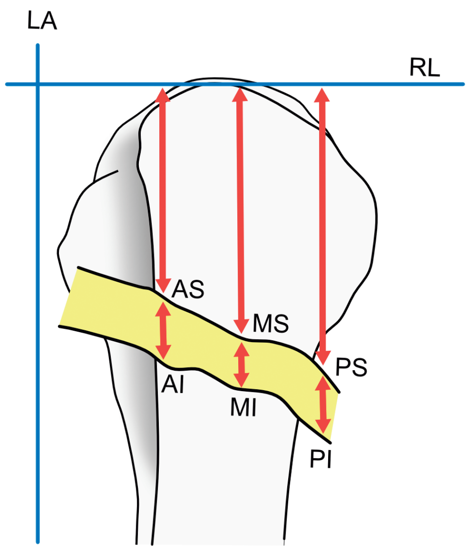

Fig. 2 The distance between the top of the greater tuberosity and the neurovascular bundle was measured at six points. LA, long axis of the humerus; RL, reference line; AS, anterosuperior edge; AI, anteroinferior edge; MS, middle-superior edge; MI, middle-inferior edge; PS, posterosuperior edge; PI, posteroinferior edge.

Relationship between the neurovascular bundle and locking plates. To assess the relationship between the neurovascular bundle and proximal humeral locking plates, we drew the passage of the neurovascular bundle on the template of the locking plate. Three locking plates (PHILOS, DePuy Synthes Japan, Tokyo; MODE Proximal Humeral Plate standard, MODE-PHP, Japan Medical Dynamic Marketing, Tokyo; and HAI Proximal Humeral Plate posteriorversion type, HAI-PHP, HOMS Engineering, Nagano, Japan) were evaluated in 2 clinical settings. The plates were set at 5 mm or 10 mm distal to the superior aspect of the greater tuberosity in the left shoulder, and we examined the screw holes that were overlapped by the neurovascular bundle.

As illustrated in Fig. 3, we named the screw holes of the PHILOS as follows: A, the anterior hole of the most proximal tier; B, the posterior hole of the most proximal tier; C, the second tier; D, the third tier; E, the anterior hole of the fourth tier; F, the posterior hole of the fourth tier; G, the center hole; H, the anterior hole of the inferomedial hole; and I, the posterior hole of the inferomedial hole. The screw holes of the MODE-PHP locking plate were named in order from A, which is the most proximal hole, to J, which is the most distal hole of the proximal locking screw

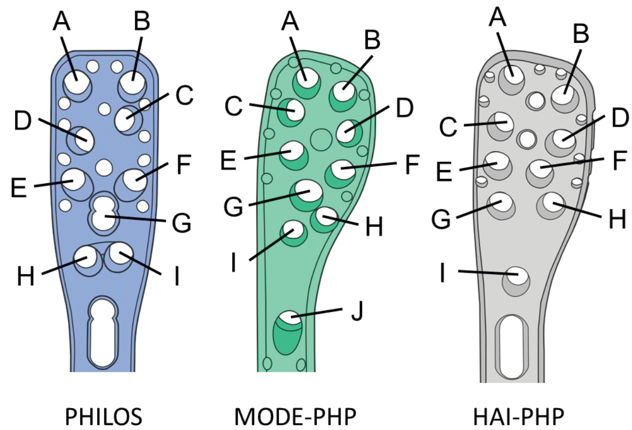

Fig. 3 The screw holes of the three locking plates for the proximal humerus were named in order, as shown, from the proximal to the distal part.

Table 1 Distance from the reference line to the neurovascular bundle in 30 shoulders of Japanese patients

	Anterior	Middle	Posterior
Superior	28.5 mm (SD 3.8)	32.6 mm (SD 4.4)	38.1 mm (SD 4.6)
Inferior	36.7 mm (SD 4.4)	41.3 mm (SD 4.5)	47.5 mm (SD 4.8)

The values are the mean ± SD distance between the superior aspect of the greater tuberosity and the superior and inferior borders of the neurovascular bundles measured at the anterior, middle, and posterior edges of the greater tuberosity.

(Fig. 3). The screw holes of the HAI-PHP plate were named from A to I in the same manner as that used for the MODE-PHP (Fig. 3).

Results

Position of the neurovascular bundle. The distances from the reference line to the neurovascular bundle are shown in Table 1. The neurovascular bundle ran from the posteroinferior to the anterosuperior direction on the lateral wall of the greater tuberosity. The mean width of the neurovascular bundle was 8.2 mm at the anterior, 8.8 mm at the middle, and 9.3 mm at the posterior edge of the greater tuberosity.

Locking plates and the neurovascular bundle. The relationship between the neurovascular bundle and three locking plates is illustrated in Fig. 4. When the

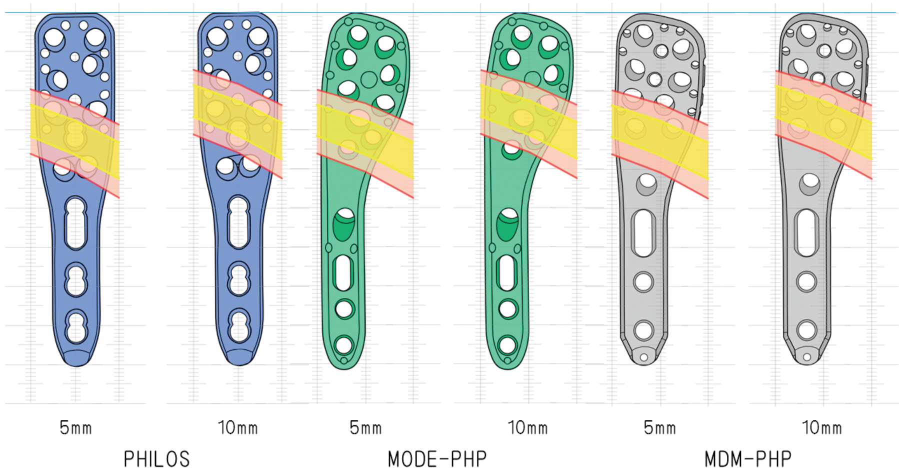

Fig. 4 The yellow zone shows the area that the neurovascular bundle passed (danger zone). The red zone shows the area that contains the standard deviation added to the danger zone (relative danger zone). Two different clinical settings, with the locking plates set at 5 mm and 10 mm distal to the top of the greater tuberosity, were evaluated.

plates were set at 5 mm distal to the greater tuberosity, the holes E, G, and I in PHILOS, holes G, H, and I in MODE-PHP, and holes G and H in HAI-PHP overlapped the danger zone. When the plates were set at 10 mm distal to the greater tuberosity, the holes E, F, and G in PHILOS, holes E, F, G, and I in MODE-PHP, and holes E, F, G, and H in HAI-PHP overlapped the danger zone.

For the MODE-PHP locking plate, hole J, which was the inferomedial support, was far from the danger zone. In the HAI-PHP plate, although hole I, which was the inferomedial support, was close to the danger zone, hole I was placed in a relatively safe area. When the standard deviation was considered, holes D, E, F, G, H, and I in PHILOS, holes E, F, G, H, and I in MODE-PHP, and holes E, F, G and H in HAI-PHP were shown to be relatively unsafe.

Discussion

Our analysis revealed that the neurovascular bundle containing the axillary nerve and posterior circumflex humeral artery and vein overlapped some screw holes of the proximal humeral locking plates. In Japanese shoulders in particular, the neurovascular bundle runs more proximal to the lateral wall of the greater tuberosity than previously thought. Moreover, the neurovascular bundle was located at a high position anteriorly and at a low position posteriorly.

Gardner *et al.*, using cadaveric specimens in North America, reported that the distance from the lateral prominence of the greater tuberosity to the superior border of the axillary nerve ranged from 34.0 to 37.0 mm [13]. Their results seem to correspond with our measurements at the middle of the greater tuberosity, which ranged from 28.2 to 37.0 mm. This means that the axillary nerve is located about 6 mm proximally in Japanese shoulders compared to North American shoulders. These findings seem useful for shoulder surgery using the deltoid-splitting approach.

Our findings also demonstrated that the neurovascular bundle had an approx. 10-mm width at the lateral wall of the greater tuberosity. Each branch of the axillary nerve and the posterior circumflex humeral artery is narrow and thin; however, they diverge and spread at the peripheral area [12]. Thus, this neurovascular bundle should be treated a 'wide zone,' and nerve damage here should be carefully avoided during surgery.

Safe area. Our results showed that among the three different locking plates, only 3 or 4 proximal screws were completely safe for insertion. Although several reports have shown the usefulness of an external guide for percutaneous screw insertion [8,10], percutaneous screw insertion for the middle part of the plate should be considered unsafe in light of our present results. For safe screw insertion, the arm position, especially the shoulder abduction angle, should be considered because the position of the neurovascular bundle changes in the shoulder abduction angle [14]. In shoulder abduction, the distance between the lateral acromial edge and the axillary nerve decreases. Moreover, the distance from the lateral edge of the acromion to the greater tuberosity becomes smaller, and thus the distance from the top of the greater tuberosity and the axillary nerve increases. This means that the 'safe' area should become wider in shoulder abduction. We did not assess the position of the neurovascular bundle in different shoulder positions. Consequently, the best arm position for screw insertion was not clarified, and further study is needed regarding this question.

Importance of the inferomedial support. The inferomedial support screws are considered important for the stability of the inferomedial region of the proximal humerus. Osterhoff *et al*. reported the influence of the calcar screw in a clinical study [15]. A significant loss of reduction was observed in patients treated without calcar screws compared to patients treated with calcar screws. Gardner *et al*. also reported the importance of inferomedial screws for maintaining fracture reduction [1].

Our study showed that the axillary nerve runs slightly proximal to the screw holes of the inferomedial support of the proximal humeral locking plates, especially in the MODE-PHP and HAI-PHP, and that the inferomedial screws may be safely inserted.

Limitations. This study has some limitations, which include its small sample size and large age distribution. The anatomical features studied might vary with body parameters such as height, weight, and body mass index. Moreover, proximal humeral fractures frequently occur in elderly women, and thus specific data should be collected for elderly women. However, such elderly female patients occasionally experience a rotator cuff tear, and a rotator cuff tear is a common cause of the superior translation of the humeral head, which might affect the relationship between the greater tuberosity and the axillary nerve.

In conclusion, the screws of the proximal humeral locking plate should be inserted carefully to avoid damage to the axillary nerve and the posterior humeral circumflex artery and vein. In particular, the screw holes into which screws could be safely inserted were three or four in the most proximal part. Based on the results we observed with the MODE-PHP and the HAI-PHP, the inferomedial support screws were relatively safe for screw insertion.

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