Establishing safe zones to avoid nerve injury in the posterior minimally invasive plate osteosynthesis for humerus fractures: a magnetic resonance imaging study

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Background: Safety zones to avoid nerve injury at proximal incision of posterior minimally invasive plate osteosynthesis for humerus fracture have been scarcely studied. The purpose of this study was to describe the location of axillary and radial nerves (RN) in magnetic resonance imaging to establish safety zones.

Methods: Fifty-two magnetic resonance imaging studies of the entire humerus were reviewed. The mean age was 50.6 ± 12.1 years, with 37 female patients. The distance of the axillary nerve (AN; distal portion, humeral midpoint) and RN (medial border, midpoint, and lateral border of the humerus) was measured in relation to the posterolateral acromion angle, acromioclavicular axis, and transepicondylar axis. Univariate analysis (Student’s t test) and a multivariate analysis (linear regression) were performed. P values < .05 were considered significant.

Results: The AN location at the humerus was 54.9 ± 6.4 mm (20.1% humeral length [HL]) in relation to posterolateral acromion angle and 63.2 ± 6.1 mm (23.2% HL) in relation to acromioclavicular axis. The RN location was 100.2 ± 17.1 mm (36.6% HL) at the humerus medial border, 118.0 ± 21.5 mm (43.1% HL) at the humerus midpoint, and 146.0 ± 24.4 mm (53.6% HL) at the humerus lateral border. In relation to transepicondylar axis, it was 175.4 ± 15.6 mm (64.3% HL), 156.0 ± 19.0 mm (57.2% HL), and 127.4 ± 21.2 mm (46.7% HL), respectively. Nerves location was related to HL, independent of gender.

Conclusion: The main finding of our study is that the location of the AN and RN in relation to the humerus is related to the HL and can be used to predictably define the safe zones to avoid nerve injury in the proximal incision of posterior minimally invasive plate osteosynthesis for humerus fractures.

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Minimally invasive plate osteosynthesis (MIPO) has advantages over conventional techniques. MIPO emphasizes minimal soft tissue dissection, indirect reduction techniques, and bridge plate fixation, improving soft tissue management and preservation of blood supply. MIPO for humeral shaft fractures yields functional outcomes similar to those of open reduction, with significantly less blood loss, shorter operative duration, and a lower incidence of nonunion, radial nerve (RN) palsy, and infection.

In distal third humeral shaft fractures, single column osteosynthesis, using the triceps sparing posterolateral approach, has reported excellent functional results and low complication rates. A cadaveric study demonstrated the safety and feasibility of using an extra-articular distal humerus plate with the posterior MIPO technique. The risk of RN injury can be minimized through careful dissection at proximal incision, considering that the nerve crosses the medial border of the humerus at 31.7%-45.6% of the humeral length (HL). Gallucci et al reported clinical results for posterior MIPO with segmental isolation of the RN. The proximal incision was made in the posterior aspect of the arm, 10 mm above the olecranon fossa.
cm distal to the posterolateral angle of the acromion (PLAA), and only one patient (4.8%) developed transient RN palsy.12

However, the safety zones in the proximal incision relative to the position of the axillary and RNS have been rarely studied. The purpose of this study was to describe the location of the axillary and RNS in magnetic resonance imaging (MRI) of the humerus and to establish safety zones for the proximal incision in the posterior MIPO technique.

Materials and methods

Sample

All MRI scans from our institutional database were retrospectively reviewed to analyze the location of the axillary and RNS. The main MRI indication was shoulder pain. We included scans showing the entire humerus and acromion of skeletally mature patients. We excluded scans of poor quality to identify major peripheral nerves and studies lacking complete images necessary to cross-reference nerve location, artifacts, and traumatic, tumorous, or infectious bone pathologies. Ultimately, 52 MRI scans were included. The mean age was 50.6 years (standard deviation, 12.1; range, 28-84 years), with 37 female and 15 male patients. The 59.6% were right handed (Table I).

MRI data acquisition and processing

The patients were placed in a supine anatomic position (Gantry tilt 0°) with elbow in full extension and scanned in a Philips Achieva 1.5T MRI machine (Philips Healthcare, Best, the Netherlands). MRI sequences included diffusion-weighted images with fat saturation and T1- and T2-weighted images in the axial, sagittal, and coronal sequences included diffusion-weighted images with fat saturation. The scans were analyzed with RadiAnt DICOM Viewer 2020.1.1 (Medixant, Poznan, Poland).

Morphometric measurements

Two independent observers (fellowship-trained shoulder and elbow surgeon and a shoulder and elbow fellow) measured the HL, the location of the axillary nerve (AN) in relation to a surgical anatomical landmark (PLAA) and a fluoroscopic landmark (acromioclavicular axis [ACA]), and the location of the RN in relation to a surgical anatomical landmark (PLAA) and a fluoroscopic landmark (transsepicondylar axis [TEA]). These measurements were made in T1-weighted MRI coronal slices with sagittal and axial images to cross-reference nerve location. For reproducibility evaluation, all MRIs were remeasured 4 weeks later.

The HL was defined as the straight line distance between PLAA and the lateral epicondyle (2D HL). The number of coronal imaging slices between these 2 points was recorded for later calculation of “3D HL” (Fig. 1).

The AN location was defined as the straight line distance between the PLAA and the most inferior branch of the AN at the humerus midpoint. The number of coronal imaging slices between these 2 points was recorded for later calculation of “3D AN.” ACA was defined as the straight horizontal line passing through the inferior aspect of the clavicle to the inferolateral point of the acromion. The perpendicular line distance between the AN to the ACA was recorded (Fig. 2).

The RN location was defined as the straight line distance between the PLAA and 3 distinct positions: where it crossed the medial cortex of the humerus, where it crossed the middle point of the humerus, and where it crossed the lateral cortex of the humerus. The number of coronal imaging slices between these points was recorded for later calculation of “3D RN.” Also, the perpendicular line distance of the RN to the TEA was measured at these 3 locations. The TEA was defined as the longest distance between the most prominent points of the medial and lateral epicondyles on coronal images (Fig. 3).

Calculation of 3D distance

Osseous anatomical landmarks and the location of a peripheral nerve were infrequently in the same coronal slice. Therefore, to determine the 3D distance between 2 points on an MRI, we used trigonometric correction (Pythagoras theorem).20

Statistical analysis

The results were analyzed with Stata BE17. The data presented normal distribution (Shapiro-Wilk test) and were presented as mean and standard deviation. The coefficient of variation (CV) was calculated. Differences between measurements were evaluated with a univariate analysis (Student’s t test) and a multivariate analysis (linear regression). P values <.05 were considered statistically significant. The intra- and inter-observer correlations were evaluated with the intraclass correlation coefficient (ICC). The study was approved by the ethics committee of our institution.

Results

The mean value of the HL was 273.2 ± 17.2 mm, and significant differences were found between females and males (267.8 ± 15.3 mm vs. 286.5 ± 14.5 mm; P = .0002; Table I). The location of the AN from the PLAA was 54.9 ± 6.4 mm (20.1 ± 2.0% HL; Table II), and from the ACA, it was 63.2 ± 6.1 mm (23.2 ± 2.2% HL; Table III). No significant differences were found between 2D and 3D measurements (Table III).

The location of the RN from the PLAA was 100.2 ± 17.1 mm (36.6 ± 5.2% HL) at the medial humerus border, 118.0 ± 21.5 mm (43.1 ± 6.7% HL) at the middle humerus, and 146.0 ± 24.4 mm (53.6 ± 7.7% HL) at the lateral humerus border (Table IV, Fig. 4). The path of the RN attached to the humerus was 45.8 ± 14.6 mm (range, 14.9-80.1 mm). No significant differences were found between 2D and 3D measurements (Table IV).

The location of the RN from the TEA was 175.4 ± 15.6 mm (64.3 ± 5.6% HL) at the medial humerus border, 156.0 ± 19.0 mm (57.2 ± 6.8% HL) at the middle humerus, and 127.4 ± 21.2 mm (46.7 ± 7.8% HL) at the lateral humerus border (Table V). The location of the AN from the PLAA and from the ACA showed statistically significant differences between males and females (Table VI). The RN only showed statistically significant differences between males and females in relation to the PLAA (Table VI). When adjusting for the HL, statistically significant differences were only observed according to gender in the location of the AN in relation to the acromion (Table VI).
When adjusting for the location of both nerves through a linear regression model, considering age, gender, and HL, a significant correlation of both nerves with the HL was observed, independent of gender. In the AN, a correlation with age was also observed (Table VII). Regarding the intra- and inter-observer correlations, the mean intraobserver ICC was 0.91 ± 0.09, and the mean interobserver ICC was 0.81 ± 0.26 for all measures (Table VIII).

Discussion

The main finding of our study is that the location of the axillary and RN in relation to the posterior aspect of the humerus is related to the HL and can be used to predictably define the safe zones to avoid nerve injury in the proximal incision of posterior MIPO for humerus fractures.

Regarding the location of the AN, both references presented CVs around 10% (range, 9.5-11.7). Considering the excellent intra- and inter-observer correlations, the low CV is attributed to minimal anatomic variability. Furthermore, because no differences were found between the 2D and 3D measurements, the use of the PLAA would be adequate because it is a reliable palpable anatomic landmark.

Several studies have used the HL as a reference to describe the proportional distance between neurovascular structures and osseous landmarks. In our study, when adjusting for the HL, the anatomic variability of AN is maintained, probably associated with a more proximal location and a shorter and perpendicular trajectory.

Jiamton et al found an average distance of 47.9 mm from the PLAA (17.5% HL), similar to our findings. The HL of their sample (268.6 mm) was similar to ours (273.2 mm).

In relation to the location of the RN, the PLAA reference presented CVs around 16.4% (range, 14.1-18.2), which is likely associated with higher anatomic variability and a longer path. In contrast, the TEA reference presented a variability around 12.5% (range, 8.7-16.7). The variability decreased when adjusting for the HL, with the “medial RN” being the least variable in both measurements. Although no differences were found between the 2D and 3D measurements, the fluoroscopic reference is the most reliable.

Jiamton et al found an average distance of 104.7 mm between the PLAA and the location where the RN crossed the medial border of the humerus (39% HL), similar to our findings. Yingling et al also evaluated the location of the RN in relation to the lateral epicondyle in a posterior approach; however, they identified the nerve along the lateral border of the triceps before diving deep into the brachioradialis for an average of 75.9 mm, which is a shorter distance than that found in our study (127.4 ± 21.2 mm). This discrepancy is likely associated with the fact that the RN was...
measured at the point where it crosses the intermuscular septum. Our measurements were made where the RN crosses the posterior cortex, somewhat more proximally.

Various anatomic studies described that the RN pierces the lateral intermuscular septum at an average range of 102-125 mm proximal to the lateral epicondyle. However, in the posterior MIPO approach, the relevant position is the path of the RN in relation to the posterior cortex of the humerus. Furthermore, most of these studies evaluate the use of lateral approaches. Reported measurement differences may have been due to these different references chosen for the proximal measurement or to variability in the course of the RN in the distal aspect of the humerus.

In all the measurements made, significant differences were found in relation to gender (Table VI). However, when adjusting for the HL, only the gender-based difference in the location of the RN, as evaluated by fluoroscopy, remained significant. When adjusting for age, gender, and HL, multivariate analysis demonstrated a gender-independent association of the location of both nerves with the HL. Furthermore, the position of the AN was inversely correlated with age, probably associated with deltoid muscle atrophy or elevation of the humeral head secondary to rotator cuff disease. Also, the HL is more relevant in the position of the RN than the AN, which is likely due to the most proximal location, trajectory, and anatomic variability.

The anatomic relationship of the RN to the medial and lateral epicondyles and the TEA has been previously described. Despite the lower variability of RN measurements in relation to the TEA, it must be considered that patients present humerus fracture, so the position of this axis will vary. In patients with comminuted fractures, the use of the TEA is limited, so its practical usefulness is limited to simple fractures that can be reduced anatomically. Based on the above, we suggest the use of this value as a reference to confirm the measurements in relation to the PLAA.

The proximal safe zone to avoid nerve injury in the posterior MIPO for humerus fractures is between the AN (proximal limit) and the location where the RN crosses the lateral border of the humerus (distal limit). These limits can help avoid damage of the AN with a long to proximal plate and help selectively dissect the RN to ensure its superficial position relative to the plate.

Figure 2 Axillary nerve. Axillary nerve (AN) location was defined as the straight line distance between the posterolateral angle of the acromion (PLAA) and the most inferior branch of the AN at the humerus midpoint. (A) Inferior branch of the AN at the posterior cortex of humerus. (B) The PLAA point was copied and then pasted in the coronal slice of the AN (superior green arrow). The straight line distance between these 2 points was recorded as “2D AN.” The number of coronal imaging slices between these 2 points was recorded for later calculation as “3D AN.” The formula to calculate the position of the AN from the PLAA in mm is $24.676 - 0.147 \times \text{age (years)} + 0.146 \times \text{HL (mm)}$. (C) Acromioclavicular axis (ACA) was defined as the straight horizontal line passing through the inferior aspect of the clavicle to the inferolateral point of the acromion. (D) The perpendicular line distance between the AN to the ACA was recorded. HL, humeral length.
Radiographically, we can confirm this measurement in relation to the TEA.

It should be considered that the minimum cutaneous incision needed for proximal incision is approximately 5 cm, but this window is flexible in relation to the abundant adipose pad in the area. In relation to the above, we recommend a 50-mm incision from the crossing of the medial edge of the humerus by the RN (100.2 mm), confirming the Gallucci recommendation (Fig. 5).\textsuperscript{13}

Balam and Zahrany\textsuperscript{6} demonstrated the safety of posterior MIPO for humerus fractures in 37 patients. Only 2 patients (5.4\%) had postoperative RN palsy, but both recovered spontaneously. Gallucci et al\textsuperscript{12} reported that in a series of 21 patients with posterior MIPO, one patient developed an RN palsy that recovered 6 weeks after surgery.

At the proximal incision, the RN lies between the lateral and long heads of the triceps along the profunda brachii vessels. Dissection should be meticulous to protect the nerve. The RN and the vessels should be lifted carefully from the bone, creating as little tension as possible to ensure that the RN will not be trapped under the plate during the submuscular tunneling and the plate insertion.\textsuperscript{15} A useful anatomic landmark is the Apex of Triceps Aponeurosis.\textsuperscript{3} The RN crosses the humerus approximately 25 mm proximal to this landmark, so we must look at the most distal...
aspect of the proximal window for the Apex of Triceps Aponeurosis to identify the RN more accurately at the midpoint of the incision. Many previous anatomic studies have used cadavers. This limited sample reduced the accuracy of their results. In addition, formalin causes shrinkage and dehydration of soft tissue, which may alter anatomical measurements. Moreover, disarticulation of the shoulder joint and dissection of the RN may have affected the course of the nerve. Therefore, we conducted an in vivo anatomical study based on MRI that we believe overcomes these reported drawbacks. In addition, the study of the location of the nerves with MRI showed excellent intra- and inter-observer correlations, which allows us to attribute variability to anatomic characteristics.

This study had several limitations, including humerus without fracture, its retrospective design, and the fact that it was performed at a single center. Nevertheless, the absence of fracture mainly affects measurements related to TEA because the indication for posterior MIPO includes those cases with fractures distal to the RN, so the measures from the acromion should not be affected; in any case, it is a consideration before its application to clinical practice. It would be advisable to analyze anatomic variations in cases of patients with humerus fracture.

Table IV
The location of the radial nerve from the posterolateral angle of the acromion.

|                      | Medial radial nerve location | Middle radial nerve location | Lateral radial nerve location |
|----------------------|------------------------------|------------------------------|------------------------------|
|                      | 2D (mm) 3D (mm) HL (%)       | 2D (mm) 3D (mm) HL (%)       | 2D (mm) 3D (mm) HL (%)       |
| Mean                 | 100.2 101.0 36.6             | 118.0 118.7 43.1             | 146.0 146.5 53.6             |
| SD                   | 17.1 16.9 5.2               | 21.5 21.3 6.7               | 24.4 24.3 7.7               |
| CV (%)               | 17.1 16.7 14.1             | 18.2 17.9 15.7             | 16.7 16.6 14.4             |
| Min                  | 60.2 62.3 25.6             | 71.4 73.2 30.4             | 79.6 81.2 34.6             |
| Max                  | 151.2 151.6 49.6           | 180.3 180.6 59.2           | 212.4 212.7 69.8           |
| 95% CI               | 95.5-105.0 96.5-105.7 35.2-38.0 | 112.0-124.0 112.9-125.0 41.2-45.0 | 139.2-152.8 139.8-153.3 51.4-55.7 |
| SW P value           | .6273 .6108 .9008          | .3780 .3705 .3728          | .8510 .8586 .3126          |
| Two-tailed P value   | .107                     | .8703                     | .9094                     |

2D, two dimensional; 3D, three dimensional; HL, humeral length; SD, standard deviation; CV, coefficient of variation; Min, minimum; Max, maximum; CI, confidence interval; SW, Shapiro-Wilk.

Figure 4 Radial nerve location. The location of the radial nerve (RN) from the posterolateral angle of the acromion (PLAA) was 100.2 ± 17.1 mm (36.6 ± 5.2% humeral length [HL]) at the medial humerus border, 118.0 ± 21.5 mm (43.1 ± 6.7% HL) at the middle humerus, and 146.0 ± 24.4 mm (53.6 ± 7.7% HL) at the lateral humerus border. The formula to calculate the position of the RN from the PLAA in mm is 0.611 × HL (mm) – 62.165. (A) Boxplot distribution of location of RN from PLAA (mm). (B) Boxplot distribution of location of RN from PLAA (% HL). (C) Boxplot distribution of location of RN from transepicondylar axis (TEA).

Table V
The location of the radial nerve from the transepicondylar axis.

|                      | Medial radial nerve location | Middle radial nerve location | Lateral radial nerve location |
|----------------------|------------------------------|------------------------------|------------------------------|
|                      | 2D (mm) HL (%)              | 2D (mm) HL (%)              | 2D (mm) HL (%)              |
| Mean                 | 175.4 64.3                  | 156.0 57.2                  | 127.4 46.7                  |
| SD                   | 15.6 5.6                    | 19.0 6.8                    | 21.2 7.8                    |
| CV (%)               | 8.9 8.7                     | 12.2 12.0                   | 16.6 16.7                   |
| Min                  | 131.8 50.7                  | 108.3 41.1                  | 91.2 30.4                   |
| Max                  | 213.8 77.5                  | 196.0 70.8                  | 177.1 66.5                  |
| 95% CI               | 171.0-179.7 55.3-59.1       | 150.7-161.3 55.3-59.1       | 121.3-133.3 44.6-48.9       |
| SW P value           | .2466 .5085                 | .7856 .3225                 | .5738 .9341                 |

2D, two dimensional; HL, humeral length; SD, standard deviation; CV, coefficient of variation; Min, minimum; Max, maximum; CI, confidence interval; SW, Shapiro-Wilk.
Table VI  
| Location of axillary and radial nerves by genre. | AN from the PLAA | RN from the PLAA (MRNL) | AN from the ACA | RN from TEA (MRNL) |
|-----------------------------------------------|------------------|------------------------|-----------------|-------------------|
| Mean (mm)                                     | Female           | Male                    | Female          | Male              |
|                                               | 53.2             | 59.2                    | 97.2            | 107.5             |
|                                               | 6.1              | 5.2                     | 17.7            | 13.4              |
| 95% CI                                        | 51.1-55.2        | 56.4-62.1               | 91.3-103.1      | 100.1-114.9       |
| SW P value                                    | .6448            | .9557                   | .2892           | .2845             |
| Two-tailed P value                            | .0014*           | .0481*                  | .0000*          | .1923             |
| HL (%)                                        | 19.9             | 20.7                    | 36.2            | 37.6              |
| SD                                           | 2.1              | 1.8                     | 5.4             | 4.6               |
| 95% CI                                        | 19.2-20.5        | 19.7-21.7               | 34.4-38.0       | 35.0-40.2         |
| SW P value                                    | .3713            | .2623                   | .9376           | .4699             |
| Two-tailed P value                            | .1756            | .3791                   | .032*           | .2005             |

AN, axillary nerve; PLAA, posterolateral angle of the acromion; RN, radial nerve; MRNL, medial radial nerve location; ACA, acromioclavicular axis; TEA, transepicondylar axis; SD, standard deviation; CI, confidence interval; SW, Shapiro-Wilk; HL, humeral length.

*Statistically significant difference between female and male.

Table VII  
| Linear regression for axillary and radial nerve location. | Coefficient | SE | P value |
|----------------------------------------------------------|-------------|----|---------|
| Axillary nerve from the PLAA                             |             |    |         |
| Age (y)                                                   | -.147       | .061| .019    |
| Genre (female)                                           | -3.211      | 1.839| .087    |
| Humerus length (mm)                                      | .046        | .049| .004    |
| Constant                                                 | 24.676      | 14.414| .093   |
| F P value                                                | .0000       | -  | -        |
| Radial nerve from the PLAA (MRNL)                         |             |    |         |
| Age (y)                                                   | -.105       | .0163| .522    |
| Genre (female)                                           | 1.189       | 4.948| .811    |
| Humerus length (mm)                                      | 0.611       | 0.132| .000    |
| Constant                                                 | -62.165     | 38.787| .116   |
| F P value                                                | .0001       | -  | -        |

PLAA, posterolateral angle of the acromion; SE, standard error; MRNL, medial radial nerve location.

Table VIII  
| Intraobserver–interobserver correlation. | ICC intra | ICC inter |
|------------------------------------------|-----------|-----------|
| 2D humeral length                        | .980      | .982      |
| 2D axillary nerve location               | .976      | .934      |
| ACA—axillary nerve                       | .779      | .838      |
| 2D medial radial nerve location          | .979      | .974      |
| 2D middle radial nerve location          | .983      | .913      |
| 2D lateral radial nerve location         | .833      | .942      |
| TEA—medial radial nerve location         | .733      | .405      |
| TEA—middle radial nerve location         | .950      | .960      |
| TEA—lateral radial nerve location        | .975      | .303      |

ICC, intraclass correlation coefficient; Intra, intraobserver; Inter, interobserver; ACA, acromioclavicular axis; TEA, transepicondylar axis.

Figure 5 Proximal incision for posterior minimally invasive plate osteosynthesis. Considering our results, we recommend a 50-mm incision from the crossing of the medial edge of the humerus by the radial nerve (100.2 mm distal to the PLAA, posterolateral acromion angle) for a direct visualization and protection. PLAA, posterolateral angle of the acromion.

corroborated with studies that evaluated the impact of the position of the shoulder and elbow.

Conclusion

The main finding of our study is that the location of the axillary and RN in relation to the posterior aspect of the humerus is related to the HL and can be used to predictably define the safe zones to avoid nerve injury in the proximal incision of posterior MIPO for humerus fractures. Considering the PLAA reference, the proximal safe zone area would be between 54.9 mm of the AN (20.1% HL) and 146 mm of the RN (53.6% HL).

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changes in the localization of the RN at the posterior aspect of the humerus with elbow position.2,3 Hackl et al determined that with 90° of elbow flexion, the distance of the RN from the anterior edge of the capitellum changed, on average, by 3.6 mm.15 Recently, Chen et al noted that the RN excursion is doubled as the elbow is flexed from 0° to 90°.12 We believe that the elbow position had no influence on the position of the RN, as it crossed the posterior humerus cortex because it is tightly adhered.

Also, the position of the shoulder and its influence on the location of the AN has been scarcely evaluated. Samart et al reported that the average distance from the lateral acromial edge to the AN at a shoulder abduction of 45° and 90° were 57.1 and 52.9 mm, respectively.2,3 Bailie et al reported that the distance between the AN and the PLAA averaged 65 mm and decreased by an average of 14 mm (22%) with the shoulder.5 Our results must be corroborated with studies that evaluated the impact of the position of the shoulder and elbow.

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