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A new risk to the axillary nerve during percutaneous proximal humeral plate fixation using the Synthes PHILOS aiming system

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Background: Percutaneous aiming arms have been developed to minimize injury during placement of submuscular proximal humerus plates. The purpose of this study was to determine the risk of axillary nerve injury during percutaneous proximal humeral plate fixation using the Synthes PHILOS aiming system.
Methods: By use of 10 fresh-frozen cadavers (20 shoulders), a 3.5-mm locking compression proximal humeral plate was fixated percutaneously to the humerus through a lateral deltoid-splitting approach using the PHILOS aiming guide. Dissection of the axillary nerve was then carried out, and measurements of its relation to the screw holes in row A through row G of the plate were taken. The lateral acromion–to–axillary nerve distance was also measured.
Results: The axillary nerve traversed row D in every shoulder, whereas it crossed over row C in 11 shoulders and both holes in row E in 16 shoulders. The closest distance to the axillary nerve achieved was 4.5 mm, corresponding to the distal (left) screw in row B. A significant negative correlation was found for the distance from the nerve to the closest proximal and distal screws (row B and row G, respectively) in both right shoulders ($\rho = -0.797$; 95% confidence interval, –0.916 to –0.548) and left shoulders ($\rho = -0.615$; 95% confidence interval, –0.831 to –0.237).
Conclusion: The axillary nerve traverses rows C, D, and E of the proximal humeral plate using the PHILOS aiming system. Importantly, our study is the first to demonstrate that the axillary nerve crosses over row C. Left-sided plate screws also came in closer proximity to the axillary nerve than right-sided plate screws.
Level of evidence: Anatomy Study; Cadaveric Dissection

Keywords: Axillary nerve; Synthes PHILOS; proximal humerus; Percutaneous; Nerve risk; humeral plate fixation

Proximal humeral fractures are a common injury in orthopedics, accounting for approximately 5% of all adult fractures. They remain the second most common fracture of the upper extremity, and they are the third most common fracture in patients older than 65 years, following hip and

Institutional review board approval was not required for this cadaveric study.

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distal radial fractures.[1,2] The majority of these fractures are a result of a moderate-energy fall from standing in a patient with low bone density.[11,19]

Several treatment options exist for proximal humeral fractures. Most proximal humeral fractures can be treated nonoperatively if they are either nondisplaced or minimally displaced.[14,15] However, for the nearly 20% of displaced proximal humeral fractures that may benefit from surgery, no single operative approach is considered the standard of care.[7,15] Although a variety of options—such as locked plating, screw fixation, intramedullary nailing, and arthroplasty—exist, clinical outcomes are frequently less than ideal.[13,18] Therefore, it is paramount to understand the risks and benefits of each treatment option available. With the relative ease and efficacy of locking plate technology, the use of plating systems for the treatment of proximal humeral fractures has become more widespread.

Different surgical approaches, such as deltopectoral and lateral deltoid splitting, are associated with the locking plating system in proximal humeral fractures. Although the deltopectoral approach to the shoulder has been the utilitarian approach for accessing proximal humeral fractures, there has been concern regarding the amount of soft-tissue stripping and devascularization of bone.[1,7,16,17] Lately, the lateral deltoid-splitting approach has gained popularity for its simplicity and its relative lack of soft-tissue stripping. However, this approach may cause potential nerve injury owing to the submuscular location of the axillary nerve.[1,8,17,19,20] To avoid this complication, several percutaneous aiming arms that guide screw placement to the proximal humeral locking plate during a submuscular approach have been developed.

The purpose of this study was to determine the location of the axillary nerve relative to the 3.5-mm Locking Compression Plate (LCP) Proximal Humerus Plate (Synthes USA, West Chester, PA, USA) when using the percutaneous PHILOS aiming system (Synthes USA) in the setting of a lateral deltoid-splitting submuscular approach. We hypothesized that the axillary nerve would course through the zone protected by the PHILOS aiming system (rows C-F).

Materials and methods

An anatomic study was performed on 20 fresh-frozen cadaveric shoulders (5 male and 5 female cadavers; mean age, 74 years; age range, 53-99 years) without any evidence of shoulder pathology. The dissections were performed by an orthopedic surgery resident in the fourth year of postgraduate training and were reviewed by an attending orthopedic surgeon. The bony landmarks of the acromion were marked. A splitting approach was then performed with a 5-cm incision from the midpoint of the lateral acromion distally along the lateral aspect of the deltoid. Dissection was carried down through the deltoid fibers to expose the underlying subdeltoid bursa, and the deltoid was then elevated off the proximal humerus distally using blunt dissection. During dissection for standard minimally invasive plate osteosynthesis, placement of the plate inherently involves release of some of the deltoid insertion to sear the plate directly on the bone. The axillary nerve was identified along the undersurface of the deltoid muscle with direct finger palpation. Once the location of the nerve was confirmed, a 3.5-mm LCP Proximal Humerus Plate (length, 114 mm; 5-hole plate) with its attached PHILOS aiming system was inserted in a submuscular manner along the lateral surface of the proximal humerus (Fig. 1). The 3.5-mm LCP Proximal Humerus Plate was chosen for our study because the PHILOS aiming system was designed specifically for this plate and because previous studies investigating the risk to the axillary nerve used this same plate.

The manufacturer's technique guide offers 2 reference points for the appropriate position of the plate during fixation.[21] One option is to place the plate approximately 8 mm distal to the rotator cuff insertion on the upper edge of the greater tuberosity. The second option is to position the plate 5 mm below the tip of the greater tuberosity. Understanding these 2 options, we decided to place the plate 5 mm below the tip of the greater tuberosity but also noted the rotator cuff insertion to avoid placing the plate too proximally. Once the plate was positioned, we made minor adjustments to seat the plate properly on the humerus owing to bony anatomic variations. We then held the plate proximally with the placement of a Kirschner wire under direct visualization. In the operating room, we would use fluoroscopy to help align the plate to the humeral shaft distally. However, because of the inaccessibility of fluoroscopy in the anatomy laboratory, a small incision was made over the most distal aspect of the plate to allow appropriate alignment and seating of the plate under direct visualization. The appropriate position of the plate was visually confirmed again after completion of our dissection. Any inappropriately positioned plates were excluded. A second wire was then placed to secure the plate distally and prevent rotation. By use of the available holes in the aiming arm with its corresponding percutaneous sleeves, a small stab incision through only skin and subcutaneous tissue was made. Next, the deltoid fibers were split bluntly down to the plate using a straight hemostat. The percutaneous sleeve was then inserted through the incision and screwed into the plate (Fig. 2). The outer cortex was drilled through the sleeve, and the inner drill sleeve was removed. Finally, a 3.5-mm locking screw was placed through the outer sleeve and secured into the plate. This process was repeated until all the available screws permitted by the aiming arm were placed.

After placement of the screws, the aiming arm was detached from the plate. The initial 5-cm longitudinal incision was then extended distally, and the deltoid muscle was carefully dissected longitudinally to identify the axillary nerve (Fig. 3). The plate was assigned left and right borders, and the screw holes in the plate were labeled row A through row G in a similar fashion to previous studies and the Synthes surgical technique guide.[10,17,19] Rows with 2 screw holes at the same level were labeled left or right (eg, row B left and row B right). The screw holes distal to row G were disregarded from our analysis because they were too distal from any potential injury to the axillary nerve. Distance measurements were performed from the closest border of any screw hole to the closest point along the axillary nerve using a digital caliper (Cen-Tech, Calabasas, CA, USA). Taking into account that finding the exact location of the nerve over the plate prior to dissection is difficult and that the nerve is also mobilized during the surgical approach, we considered any screw hole over which the nerve could be gently transposed to be covered by the nerve. To compare baseline anatomy in the region, measurements were also taken

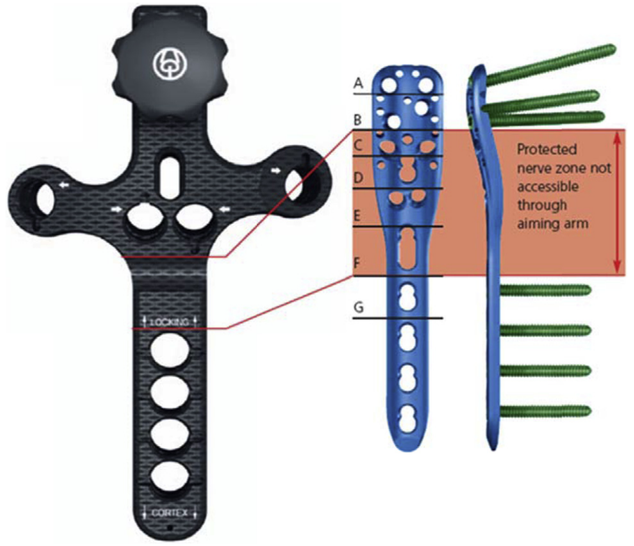

Figure 1 Synthes 3.5-mm Locking Compression Plate Proximal Humerus Plate with its PHILOS aiming system. The screw holes are labeled row *A* through row *G*.

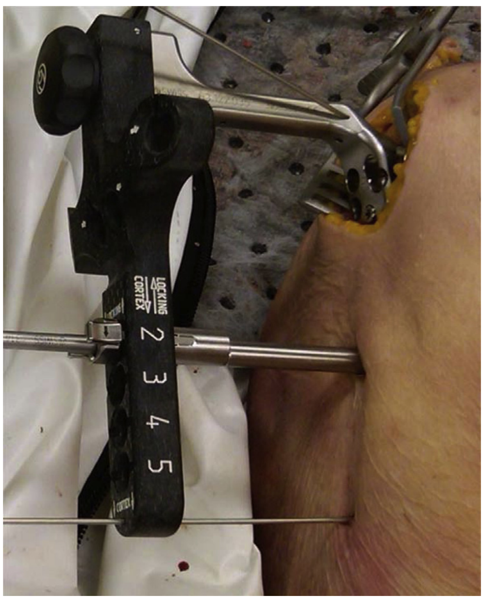

Figure 2 Shaft screws are placed percutaneously to the 3.5-mm Locking Compression Plate Proximal Humerus Plate through the drill sleeve in the PHILOS aiming system.

from the lateral border of the acromion to the nerve as it crossed the midline of the plate.

Statistical analysis

Statistical analysis was performed using Spearman rank correlation to determine the relationship between the 2 closest proximal and distal aiming arm screw holes and the axillary nerve. A 95% confidence interval (CI) was set to determine significance.

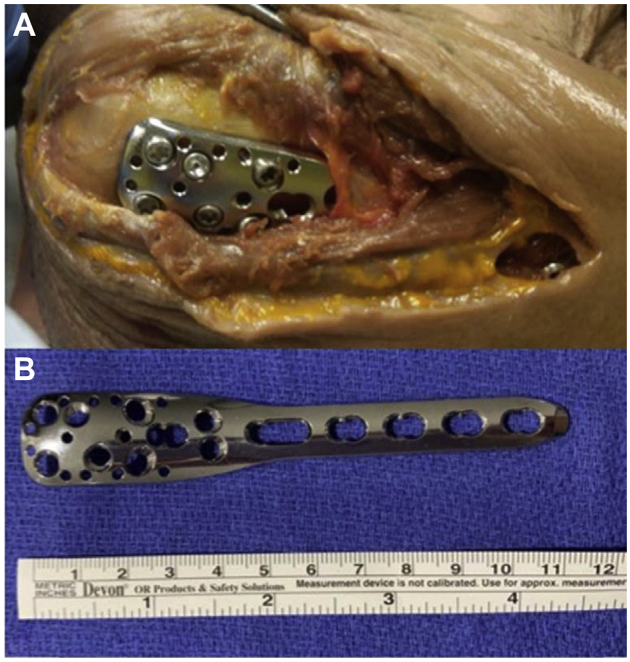

Figure 3 The axillary nerve is dissected through a lateral approach, and the distance from each screw hole of the plate to the closest edge of the axillary nerve is measured. (**A**) In this case, the nerve courses over row E. (**B**) Example of the 3.5-mm LCP Proximal Humerus Plate (length, 114 mm; 5-hole plate) used in this study, alongside a ruler for reference.

Results

Once dissected, the axillary nerve crossed over the row C, D, and E screw holes of the 3.5-mm proximal humeral locking plate. The nerve traversed row C in 11 shoulders (55%), which consisted of 5 female shoulders (4 right and 1 left) and 6 male shoulders (4 right and 2 left). In 4 shoulders, the axillary nerve crossed both screw holes in row C, whereas the nerve traversed right row C in 6 shoulders and left row C in 1 shoulder. Row D was crossed by the nerve in all 20 shoulders, and both holes in row E were crossed in 16 shoulders. Table I displays these results.

The distances measured from each corresponding screw hole to the nerve were also recorded. Including all shoulders, the closest distance from any screw placed through the percutaneous aiming arm to the axillary nerve was 4.5 mm. This measurement was from the left screw in row B, the more distal of the 2 screws in that row. In fact, the left screw in row B consistently had the smallest measured distance to the nerve of any screw placed through the aiming arm, regardless of left or right shoulders. The mean distance to the nerve in left shoulders from the left row B screws was 11.09 mm (range, 4.5-14.71 mm), whereas the mean distance to the nerve in right shoulders from the left row B screws was 11.28 mm (range, 6.5-19.08 mm). The closest screw placed through the aiming arm distal to the nerve was in row G, which had a mean distance of 26.52

Table I Anatomic measurements

	Distance, mm										
	SP-P	Row A	Row B		Row C		Row D	Row E (L + R)	Row F (Ob)	Row G	Ac-N
			R	L	L	R					
Female 1											
L	29.66	20.26	17.94	8.68	Over	8.86	Over	Over	4.59	25.36	55
R	28.61	21.82	14.33	14.31	5.72	1	Over	Over	7.58	24.17	54
Female 2											
L	39.98	24.28	18.03	13.6	4	6.58	Over	Over	5.82	23.56	55
R	29.6	19.47	13.26	12.39	2.69	Over	Over	Over	11.84	28.67	57
Female 3											
L	30.65	21.79	17.71	11.87	3.89	7.21	Over	Over	9.85	26.98	58
R	31.31	22.48	13.85	12.56	4.38	Over	Over	Over	9.94	27.3	60
Female 4											
L	28.34	19.84	17.89	9.72	1.23	8.49	Over	Over	5.52	26.41	57
R	29.83	20.1	12.4	11.86	3.9	Over	Over	Over	11.16	26.08	59
Female 5											
L	32.12	23.62	17.67	11.4	1.5	7.3	Over	Over	6.32	22.41	60
R	29.23	19.45	13.24	12.16	3.4	Over	Over	Over	11.96	26.8	61
Male 1											
L	27.7	16.87	8.28	4.5	Over	Over	Over	3.56	17.02	31.32	60
R	27.57	15.58	8.62	6.3	Over	Over	Over	3.18	16.51	32.36	60
Male 2											
L	28.64	17.34	10.11	5.61	Over	Over	Over	2.97	16.49	33.2	58
R	27.95	17.48	10.59	6.36	Over	Over	Over	2.19	16.1	31.06	61
Male 3											
L	33.76	25.86	19.32	11.91	1.93	7.28	Over	Over	6.79	22.02	73
R	28.86	19.43	13.22	11.92	4.11	Over	Over	Over	12.09	24.93	75
Male 4											
L	34.84	25.24	20.92	14.71	6.46	8.96	Over	Over	6.9	22.78	75
R	38.1	27.8	20.52	19.08	11.04	7.47	Over	Over	3.3	19.93	77
Male 5											
L	33.49	26.11	18.79	12.6	2.83	6.18	Over	Over	9.29	26.75	68
R	28.98	19.1	11.66	11.44	3.5	Over	Over	Over	10.13	28.25	62

SP-P, distance from superior edge of plate to axillary nerve; *R*, right; *L*, left; *Ob*, oblong screw hole; *Ac-N*, distance from lateral acromion border to axillary nerve; *Over*, axillary nerve lies over respective screw hole.
All measurements correspond to the distance from the respective row to the axillary nerve.

mm (range, 19.93-33.20 mm). Measurements taken from the lateral edge of the acromion to the axillary nerve had a mean value of 62.63 mm (range, 54-77 mm). These distances are shown in Table I.

Left row B hole distances to the nerve had a significant negative correlation with row G hole distances ($\rho = -0.615$; 95% CI, –0.831 to –0.237). Right row B hole distances to the nerve also had a significant negative correlation with row G hole distances ($\rho = -0.797$; 95% CI, –0.916 to –0.548).

Discussion

Percutaneous aiming arms for proximal humeral locking plates using a submuscular approach have gained popularity given their relative ease of use and respect of soft tissue. However, with their minimal soft-tissue dissection, these constructs have a potentially increased risk of neurovascular injury. In our cadaveric study, we determined the location of the axillary nerve with respect to a percutaneously placed proximal humeral locking plate when using the PHILOS aiming system in the setting of a lateral deltoid-splitting submuscular approach.

By measuring the axillary nerve distance in relation to the fixation plate, we found that the nerve most consistently crossed over rows C, D, and E. However, the axillary nerve course observed in our study was slightly more proximal than has been previously described in the literature, which has found the nerve to cross over rows D, E, and even F.[10,17,19,20] Importantly, our study is the first to demonstrate that the axillary nerve crosses over row C. Examining the design of the PHILOS aiming system, we also found that the screw holes for row C to row F are inaccessible because the construct does not provide a percutaneous guide window. The screws placed in row G were found to be a safe distance distal to the axillary nerve in our study, which correlates with several previous reports.[1,6,10,17,19,20] On the basis of our findings, we concluded that the course of the axillary nerve ranges from row C to row F of the Synthes proximal humeral plate.[1,6,10,17,19,20]

Our result brings awareness of a new risk of nerve injury that may occur during proximal humeral plate fixation with a percutaneous aiming system. We found that the axillary nerve did traverse row C in 11 instances, which has not been shown in previous studies.[10,17,19,20] In addition, the left screw in row B consistently had the smallest measured distance to the nerve of any screw placed through the aiming arm, regardless of laterality. On the basis of our results and those of earlier studies, the inherent protective design of the Synthes percutaneous aiming system does prevent injury to the axillary nerve once the fracture is appropriately reduced. However, we recommend that the aiming system be removed to allow placement of screws into row C under direct visualization and gentle retraction. We also recommend consideration of the proximity of the axillary nerve to the left screw placed in row B.

Unlike the earlier studies on the PHILOS plate with a lateral submuscular approach, our study used the most current percutaneous aiming system. Acklin et al[1] were able to use the standard screw guide block to place the screws in the appropriate orientation; however, other studies found that the screw guide block was too bulky and tented the axillary nerve by extending too far distally along the plate.[10,20] The screw guide block extends down the plate to the level of row E; the percutaneous aiming system, on the other hand, attaches proximally and only extends to cover row B. Furthermore, this system requires less retraction of the deltoid muscle for placement in a submuscular manner because it is several millimeters thinner than the screw guide block. Overall, we caution against using this guide block system given our finding of potential axillary nerve injury in row C and the previous documentation of tenting of the nerve.[10,20] Other studies also used an older model of the Synthes aiming system, which allowed for percutaneous placement of screws in row C, and they found these screws to be on average 15.1 mm proximal to the axillary nerve.[17,20] However, our study brings awareness to the potential danger of these screw holes.

Measuring the distance of the axillary nerve to the lateral edge of the acromion, we did not find the nerve located closer than 54 mm, with a mean distance of 62.63 mm. Burkhead et al[4] found the axillary nerve to be less than 50 mm from the edge of the acromion in nearly 20% of their specimens. However, our data more closely reflect prior studies placing the nerve at the more generally recognized distance of 5 to 7 cm from the acromion.[1,3,5,6,20,23] Supporting the results of Gardner et al,[6] we also found that the axillary nerve runs obliquely across the lateral aspect of the humerus from distally to proximally as it courses posteriorly to anteriorly.

Our study has limitations that warrant mention. The sample size of 20 shoulders from 10 fresh-frozen cadavers can be considered relatively small, especially compared with studies such as that of Burkhead et al,[4] who used over 50 cadavers. However, several previous studies have used similar or smaller numbers of specimens and achieved statistical significance with their data.[3,6,9,12,19,22] A second limitation is that our study was carried out on intact humeri, so we could not take into account the soft-tissue distortion due to a fracture. Although several studies have reported acceptable results of minimally invasive plating, we wanted to confirm the location of the axillary nerve during proximal humeral plate fixation using a percutaneous screw aiming system in an ideal setting prior to introducing potential confounding variables.[8,16] In fractured humeri, adequate reduction would be paramount for the application of our study results to accurately reflect risk to the axillary nerve. In these settings, the humerus is typically shortened, which would lead us to believe that screws placed through row C would be of greater risk to the axillary nerve. Finally, on a technical note, we were unable to use fluoroscopy in the anatomy laboratory where the study was conducted. We were required to use a small incision over the distal tip of the plate to manipulate the plate and visually confirm its distal location on the humeral shaft.

Conclusion

We confirm the course of the axillary nerve to range from row C to row F of the 3.5-mm LCP Proximal Humerus Plate when using the PHILOS aiming system. Our study is the first to demonstrate that the axillary nerve crosses over row C, and we recommend that the placement of screws in this row be performed under direct visualization and gentle retraction. Consideration should also be given to the proximity of the axillary nerve to the left screw of row B.

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Disclaimer

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References

1. Acklin YP, Jenni R, Walliser M, Sommer C. Minimal invasive PHILOS-plate osteosynthesis in proximal humerus fractures. Eur J Trauma Emerg Surg 2009;35:35-9. https://doi.org/10.1007/s00068-008-7154-5
2. Baron JA, Barrett JA, Karagas MR. The epidemiology of peripheral fractures. Bone 1996;18:209S-13S.
3. Bono CM, Grossman MG, Hochwald N, Tornetta P. Radial and axillary nerves. Anatomic considerations for anatomic fixation. Clin Orthop Relat Res 2000;379:259-64.
4. Burkhead WZ, Scheinberg RR, Box G. Surgical anatomy of the axillary nerve. J Shoulder Elbow Surg 1992;1:131-6.
5. Esenyel CZ, Yesiltepe Y, Bulbul M, Bagriacik A, Kara AN. Treatment of proximal humeral fractures with open reduction and internal fixation with Kirschner wires. Acta Orthop Traumatol Turc 2001;35:10-5.
6. Gardner MJ, Griffith MH, Dines JS, Briggs SM, Weiland AJ, Lorich DG. The extended anterolateral acromial approach allows minimally invasive access to the proximal humerus. Clin Orthop Relat Res 2005;434:123-9. https://doi.org/10.1097/01.blo.0000152872.95806.09
7. Gerber C, Werner CM, Vienne P. Internal fixation of complex fractures of the proximal humerus. J Bone Joint Surg Br 2004;86:848-55. https://doi.org/10.1302/0301-620X.86B6
8. Knežević J, Mihalj M, Čukelj F, Ivanišević A. MIPO of proximal humerus fractures through an anterolateral acromial approach. Is the axillary nerve at risk? Injury 2017;48:S15-20. https://doi.org/10.1016/S0020-1383(17)30733-7
9. Kulkarni RR, Nandedkar AN, Mysorekar VR. Position of the axillary nerve in the deltoid muscle. Anat Rec 1992;232:316-7.
10. Laflamme GY, Rouleau DM, Berry GK, Beaumont PH, Reindl R, Harvey EJ. Percutaneous humeral plating of fractures of the proximal humerus: results of a prospective multicenter clinical trial. J Orthop Trauma 2008;22:153-8. https://doi.org/10.1002/ar.1092320217
11. Lee SH, Dargent-Molina P, Breart G, EPIDOS Group. Epidemiologie de l'Osteoporose Study: risk factors for fractures of the proximal humerus: results from the EPIDOS prospective study. J Bone Miner Res 2002;17:817-25. https://doi.org/10.1359/jbmr.2002.17.5.817
12. Loomer R, Graham B. Anatomy of the axillary nerve and its relation to inferior capsular shift. Clin Orthop Relat Res 1989;243:100-5.
13. Naranja RJ Jr, Iannotti JP. Displaced three and four-part proximal humerus fractures: evaluation and management. J Am Acad Orthop Surg 2000;8:373-82.
14. Neer CS II. Displaced proximal humeral fractures: I. Classification and evaluation. J Bone Joint Surg Am 1970;52:1077-89.
15. Nho SJ, Brophy RH, Barker JU, Cornell CN, MacGillivray JD. Innovations in the management of displaced proximal humerus fractures. J Am Acad Orthop Surg 2007;15:12-25. https://doi.org/10.543/00124635-200701000-00003
16. Park J, Jeong SY. Complications and outcomes of minimally invasive percutaneous plating for proximal humeral fractures. Clin Orthop Surg 2014;6:146-52. https://doi.org/10.4055/cios.2014.6.2.146
17. Saran N, Bergeron S, Benoit B, Reindl R, Harvey E, Berry G. Risk of axillary nerve injury during percutaneous proximal humerus locking plate insertion using an external aiming guide. Injury 2010;41:1037-40. https://doi.org/10.1016/j.injury.2010.04.014
18. Schlegel TF, Hawkins RJ. Displaced proximal humerus fractures: evaluation and treatment. J Am Acad Orthop Surg 1994;2:54-66.
19. Smith J, Berry G, Laflamme Y, Blain-Pare E, Reindl R, Harvey E. Percutaneous insertion of a proximal humeral locking plate: an anatomic study. Injury 2007;38:206-11. https://doi.org/10.1016/j.injury.2006.08.025
20. Stecco C, Gagliano G, Lancerotto L, Tiengo C, Macchi V, Porzionato A, et al. Surgical anatomy of the axillary nerve and its implication in the transdeltoid approaches to the shoulder. J Shoulder Elbow Surg 2010;19:1166-74. https://doi.org/10.1016/j.jse.2010.05.010
21. Synthes. 3.5mm LCP Proximal Humerus Plates Technique Guide [brochure]. West Chester, PA: Synthes; 2002.
22. Tubbs RS, Oakes WJ, Blount JP, Elton S, Salter G, Grabb PA. Surgical landmarks for the proximal portion of the axillary nerve. J Neurosurg 2001;95:998-1000.
23. Vathana P, Chiarapattanakom P, Ratanalaka R, Vorasatit P. The relationship of the axillary nerve and the acromion. J Med Assoc Thai 1998;81:953-7.