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ANTEGRADE NAILING VERSUS LOCKING PLATE OF 2-AND 3-PART PROXIMAL HUMERUS FRACTURES

HASTE INTRAMEDULAR *VERSUS* PLACA BLOQUEADA NO TRATAMENTO DA FRATURA DO ÚMERO PROXIMAL EM DUAS E TRÊS PARTES

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ABSTRACT

Objective: To evaluate and compare the proportions of complications and radiographic findings of osteosynthesis of 2- and 3-part proximal humerus fractures with two methods of treatment: third-generation antegrade nailing and locking plate. Methods: 46 patients with a mean age of 58.9 ± 16.6 years between January 2020 and January 2021 were evaluated. In sixteen cases (34.8%), antegrade nailing was used, and in thirty cases (65, 2%), a locking proximal humerus plate. The method used included the rate of complications with a minimum follow-up of 6 months after surgery and radiographic evaluation. Results: There was no difference between the groups regarding the proportion of complications (nail group 18.8%, plate group 13.3%; p = 0.681). The nail group had less residual varus loss (cervicodiaphyseal angle nail group with 132.1º ± 2.3º, plate group 123.8º ± 10.1º; p < 0.001). In the plate group, women had the lowest value (1.43 ± 0.22) of the deltoid tuberosity index (DTI) compared to men (1.58 ± 0.11) (p = 0.022). Conclusion: Osteosynthesis, with a locking plate and antegrade nailing, did not show differences in the proportion of complications. The nail group had less change in the postoperative cervicodiaphyseal angle, however, there were two serious complications with screw cut-out and varus deviation, requiring surgical reapproach. ***Level of Evidence II, Retrospective Observational Study.***

Keywords: Postoperative Complications. Fracture Fixation, Intramedullary. Fracture Fixation. Humeral Head.

RESUMO

Objetivo: Avaliar retrospectivamente e comparar proporções de complicações e achados radiográficos da osteossíntese da fratura do úmero proximal em duas e três partes com dois métodos de tratamento: haste intramedular bloqueada de terceira geração e placa bloqueada. Métodos: Foram avaliados 46 pacientes com idade média de 58,9 ± 16,6 entre janeiro de 2020 a janeiro de 2021. Em 16 casos (34,8%), utilizou-se a haste intramedular e, em 30 casos (65,2%), a placa bloqueada de úmero proximal. A avaliação incluiu a taxa de complicações com seguimento mínimo de seis meses de pós-operatório e avaliação radiográfica. Resultados: Não houve diferença significativa entre os grupos quanto à proporção de complicações (grupo haste: 18,8%; grupo placa: 13,3%; p = 0,681). O grupo haste apresentou menor perda residual em varo (ângulo cervicodiafisário: grupo haste com 132,1º ± 2,3º; grupo placa com 123,8º ± 10,1º; p < 0,001). No grupo placa, as mulheres apresentaram menor índice de tuberosidade-deltoide (DTI) (1,43 ± 0,22) em relação aos homens (1,58 ± 0,11) (p = 0,022). Conclusão: No seguimento de curto prazo, a osteossíntese, com placa bloqueada ou haste intramedular, não apresentou diferenças nas proporções de complicações. O grupo haste apresentou menor alteração do ângulo cervicodiafisário no pós-operatório; entretanto, ocorreram duas complicações graves com cut out e desvio em varo com necessidade de reabordagem cirúrgica no grupo haste. ***Nível de Evidência II, Estudo Retrospectivo Observacional.***

Descritores: *Complicações Pós-Operatórias. Fixação Intramedular de Fraturas. Fixação de Fratura. Cabeça do Úmero.*

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INTRODUCTION

Proximal humerus fracture is the third most common fracture in patients over 65 years, after hip and wrist fractures.[1] In the last 40 years, there has been an increase in its incidence, and currently it corresponds to 6% of all fractures in adults.[2] The incidence of this fracture increases about 15% per year, making it a public health concern, as does femoral neck fracture in older adults.[3]

The most common trauma mechanism is falling from standing height with support on the outstretched hand. It is more common in older women due to the higher incidence of osteoporosis in this population group. Approximately 85% of cases can be treated nonoperatively.[4] For surgical cases, there are several fixation techniques, such as Kirschner wires, antegrade nailing and internal fixation with open reduction using plates for the proximal third of the humerus.

The treatment of displaced fractures, in two and three parts, remains controversial. The most frequently used treatment options are the locking plate and the antegrade nailing.[5] Complications associated with locking plates include necrosis of the humeral head (35%), screw cut-out (57%) and pseudarthrosis (13%).[6] Osteosynthesis, with antegrade nailing, emerged as a viable option in the treatment for proximal humerus fractures, with the advantage of lower soft tissue dissection and superiority over plates in biomechanical studies for fractures in two parts of the surgical neck.[7] However, it does not lack complications. The first and second generation of antegrade nailing showed high rates of reoperations and complications, especially iatrogenic rotator cuff injuries, being discouraged by most surgeons.[8] Third generation antegrade nailing was developed to solve these problems, with a short and smaller diameter nail format with an entry point in the muscular portion of the supraspinatus, which would provide a high rate of consolidation, good clinical outcomes and low rate of complications.[9]

Given the above, this study retrospectively analyzed the complication rates of two surgical techniques: antegrade nailing and locking plate of the proximal humerus. The objective is to evaluate the differences in the rate of complications and in the radiographic results with a minimum follow-up of 6 months after the operation.

METHODS

A retrospective, non-randomized study was carried out in adults with 2- and 3-part proximal humerus fractures, according to the Neer classification,[10] subjected to surgical treatment with antegrade nailing or locking plate. In total, 50 patients operated between January 2020 and January 2021 were selected. All patients signed the Informed Consent Form to participate in this study, which was submitted for evaluation and approval by the Committee for Ethics in Research with Human Beings, registered in Plataforma Brasil (CAAE No. 48052621.5.0000.8153).

Inclusion criteria

Inclusion criteria were all adult patients with a closed 2- and 3-part proximal humerus fracture,[10] who underwent surgical treatment with a third-generation antegrade nailing or locking plate and who had a minimum follow-up of 6 months postoperatively.

Exclusion criteria

Those who had a follow-up shorter than the established one, were under 18 years, had a history of previous surgery on the affected shoulder, had insufficient data in their medical records and had refused to participate in the research were excluded.

After applying the inclusion and exclusion criteria, 46 patients were selected. The minimum postoperative follow-up for all patients was 6 months.

Sixteen patients underwent osteosynthesis with third-generation antegrade nailing (Multiloc Humeral Nail®, DePuy Synthes®, Switzerland) and thirty patients were treated with a locking proximal humerus plate (Hexagon®, Hexagon Implants®, Brazil). All patients were operated by the same group of surgeons.

Radiographic evaluation

The radiographic classification used in this study was the one described by Neer,[10] in 1970, which divides the proximal humerus into 4 parts based on the three radiographs in the shoulder trauma series. The Deltoid Tuberosity Index (DTI) is calculated through the radiographic incidence in true AP, in the superior end of the deltoid tuberosity, in which the cortical edges are parallel. The ratio of the outer cortical diameter and the inner cortical diameter defines the DTI value.[11]

The cervicodiaphyseal angle was measured according to the method described by Schnetzke et al.[12] (Figures 1 and 2) to quantify any varus or valgus deviation, based on the head-shaft anatomical value of 135°. Radiography is performed in true AP. For the purpose of this study, the difference between the measured postoperative angle and the anatomical value of 135° was established in all patients (plate and nail group). According to Fleischhacker et al.,[13] varus malpositioning, with a difference greater than 20° (< 115°) are associated with worse functional outcomes and predictor of secondary varus collapse. In addition, surgical revision may be necessary.[13]

The study of Capriccioso, Zuckerman and Egol[14] defined that proximal humerus fractures with varus displacement (< 130°) have a higher risk of postoperative complications than fractures with valgus displacement (> 135°).

Statistical analysis

Central tendency and dispersion values (mean and standard deviation) and amplitude (maximum and minimum values) were described for continuous and interval variables and, in the case of categorical variables, absolute numbers and percentages were described. The findings were stratified by antegrade nailing and plate, and the means were compared using the Student's t-test for independent samples, and the proportions were compared using the chi-squared test or Fisher's exact test (when it involved comparisons with amounts less than 5). The significance level adopted was 5%. Means of age and DTI were compared by sex, further stratified by antegrade nailing and plate. The significance level adopted was also 5%.

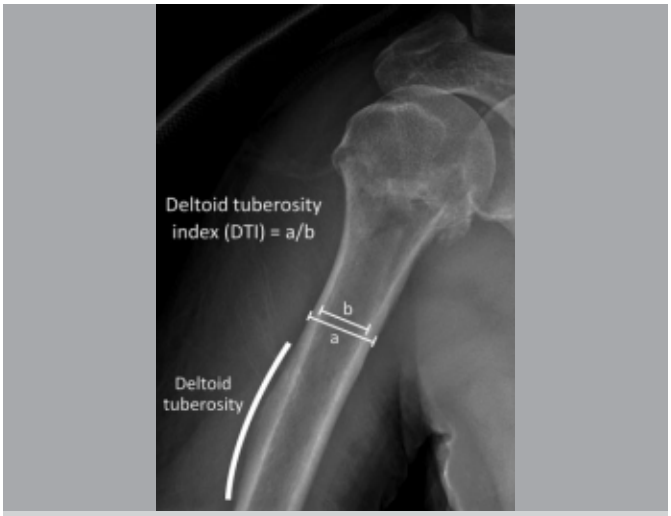

Figure 1. Calculation of the deltoid tuberosity index.

Source: Spross et al.[11]

Figure 2. Measurement of the cervicodiaphyseal angle.

Cervicodiaphyseal angle measurement method as described by Schnetzke et al.[12] As described, line A is drawn from the upper and lower edges of the articular surface. Line B is drawn from the center of the humeral head, being perpendicular to line A. Line C is drawn through the center of the diaphysis. The angle formed between lines B and C is defined as the cervicodiaphyseal angle.

Source: Schnetzke et al.[12]

RESULTS

Between January 2020 and January 2021, 50 patients underwent surgical treatment for 2- and 3-part proximal humerus fractures. Of these, four patients were excluded from the study due to insufficient documentation in medical records.

Thus, 46 patients were included in the study. Most were women (n = 26; 56.5%), with a mean age of 58.9 ± 16.6 years (21-88 years) (Table 1). Regarding the fractured side, there was a significantly higher proportion of fractures on the left side (n = 27;), with significant difference ($p < 0.05$).

There was a significant difference in relation to the postoperative cervicodiaphyseal angle, which was closer to that considered anatomical (132° × 123.5°, $p < 0.001$) in the nail group.

Regarding the deltoid tuberosity index (DTI), a significant difference was found between men and women in the plate group (1.43 × 1.58).

The decision on the number of proximal screws used in the nail and locking plate groups is based on bone quality and fracture morphology.[15] There was a significant difference regarding the number of proximal screws used between the groups, both mean (3.4 × 5.47, $p < 0.001$) and proportion by numbers.

Consolidation occurred in all patients 6 months after the operation, except for two patients who evolved with cut out and secondary varus loss in the nail group.

There was no significant difference between the need for surgical reapproach and complication rates and between the nail and plate groups (18.8% × 13.3%). The main complication in the plate group was loss of reduction with varus deviation. One patient in the plate group presented advanced and symptomatic osteonecrosis of the humeral head, undergoing reverse arthroplasty.

In the nail group, there was one case of deep infection, with a consolidated fracture, and the osteosynthesis material was removed. In two cases in the nail group, there was screw cut-out with secondary varus deviation, requiring surgical revision. One patient underwent revision for a locking proximal humerus plate (Philos®, DePuy Synthes®, Switzerland). Another 55-year-old patient, diagnosed with severe depressive disorder and with previous self-extermination attempts, was chosen to undergo Jones resection arthroplasty.

Table 1. Findings related to the operated patients (stratification by antegrade nailing and plate).

Variables analyzed	Categories or statistics	Antegrade Nailing	Plate	Total	p value
Sex (n; %)	Female	12 (75.0)	14 (46.7)	26 (56.5)	0.117
	Male	4 (25.0)	16 (53.3)	20 (43.5)	
Age (in years)	Mean (SD)	64.1 (11.6)	56.2 (18.3)	58.9 (16.6)	0.128
	Minimum; maximum	46-87	21-88	21-88	---
Neer classification (n; %)	2 parts	6 (37.5)	20 (66.7)	26 (56.5)	0.057
	3 parts	10 (62.5)	10 (33.3)	20 (43.5)	---
cervicodiaphyseal angle (in degrees)	Mean (SD)	132.1 (2.3)	123.8 (10.1)	126.7 (9.1)	< 0.001***
	Minimum; Maximum	128-136	90-136	90-136	---
Deltoid tuberosity index (DTI)	Mean (SD)	1.45 (0.12)	1.51 (0.18)	1.49 (0.16)	0.204
	Minimum; Maximum	1.25-1.62	1.00-1.79	1.00-1.79	---
Number of Screws	Mean (SD)	3.4 (0.5)	5.7 (0.5)	4.9 (1.2)	< 0.001***
	Minimum; Maximum	3; 4	5; 7	3; 7	---
Number of Screws (n; %)	3	9 (56.3)	0 (0.0)	9 (19.6)	< 0.001***
	4	7 (43.7)	0 (0.0)	7 (15.2)	
	5	0 (0.0)	10 (33.3)	10 (21.7)	
	6	0 (0.0)	19 (63.3)	19 (41.3)	
	7	0 (0.0)	1 (3.4)	1 (2.2)	
Side (n; %)	Right	10 (62.5)	9 (30.0)	19 (41.3)	0.033*
	Left	6 (37.5)	21 (70.0)	27 (58.7)	
Complications (n; %)	No	13 (81.3)	26 (86.7)	39 (84.8)	0.681
	Yes	3 (18.8)	4 (13.3)	7 (15.2)	
Surgical reapproach (n; %)	No	13 (81.3)	28 (93.3)	41 (89.1)	0.325
	Yes	3 (18.8)	2 (6.7)	7 (15.2)	

SD: standard deviation; *** $p < 0.001$; * $p < 0.05$.

Table 2. Findings related to age and deltoid tuberosity index, stratified by nailing and locking plate.

	Age (in years) Mean (SD)		Deltoid tuberosity index (DTI) Mean (SD)	
	Female	Male	Female	Male
Nail	63.7 (10.0)	65.3 (17.5)	1.46 (0.11)	1.42 (0.11)
	p = 0.822		p = 0.570	
Plate	61.9 (19.7)	51.2 (16.0)	1.43 (0.22)	1.58 (0.11)
	p = 0.111		p = 0.022*	

SD: standard deviation; * $p < 0.05$.

DISCUSSION

Although the literature shows several treatment options for 2- and 3-part proximal humerus fractures, there is no well-defined gold standard.[16] Thus, the objective of this study was to identify differences between antegrade nailing and locking plate in terms of radiographic alterations and rate of complications.

Many authors have reported several complications with the use of an antegrade nailing, such as rotator cuff injury, proximal nail protrusion, causing subacromial impingement, secondary fracture deviation and joint protrusion of locking screws.[17]

The study described by Boileau et al.[18] defined the conditions necessary to prevent these possible complications, such as the use of a straight antegrade nailing with a smaller diameter (7-8 mm), with insertion in the musculotendinous region with an entry point at the top of the humeral head approximately 10 mm

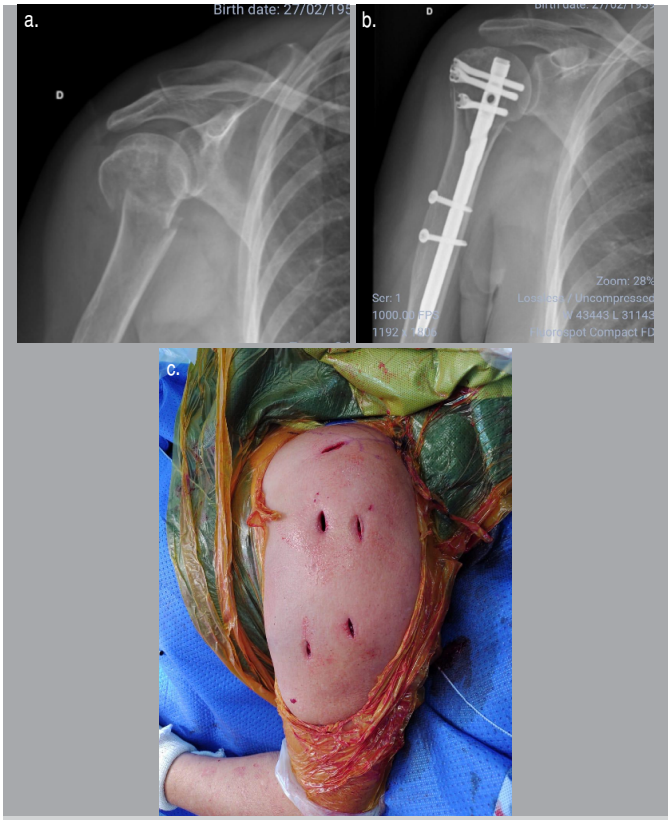

Figure 3. a. Fracture in two parts of the surgical neck; b. Postoperative radiography; c. Intraoperative appearance.

posterior and medial to the bicipital sulcus and aligned to the long axis of the diaphysis.

Several authors have addressed the comparison between treatment options in proximal humerus fractures. Shi et al.[19] performed a systematic review comparing surgical plate treatment *versus* antegrade nailing and concluded that osteosynthesis with a nail reduced the number of complications, surgical time, blood loss and postoperative osteonecrosis rate. Li et al.,[20] in their systematic review, concluded that antegrade nailing is superior to the plate in terms of surgical time and consolidation; however, there was no significant difference regarding the incidence of complications and functional outcomes.

Zhu et al.[21] performed a randomized study comparing patients treated with locking plate and antegrade nailing. They reported a higher rate of complications in the plate group (31% *versus* 4%), the main complication being screw cut-out. Plath et al.,[22] in a prospective study, found no significant differences between the plate groups *versus* antegrade nailing on functional outcomes and complication rates. Gracitelli,[23] in 2015, in a prospective clinical study, found no clinical differences between nailing and locking plate.

Biomechanical studies comparing antegrade nailing and locking plate present controversial results. Some studies show greater rigidity for the antegrade nailing for axial loading and cantilever effect in flexion, extension, varus and valgus, but its disadvantages would be, mainly, the rotator cuff injury and the difficulty to reduce the fracture.[24] Other studies showed that the locking plate was superior in terms of torsional strength and cyclic loading in varus.[25]

The most recent studies show that both the antegrade nailing and the locking plate are viable options for the treatment of proximal humerus fractures, presenting good functional results with high consolidation rates.[26,27]

The DTI value was lower in women in the plate group, which is related to poorer bone quality and predisposition to fractures. The study of Kim et al.,[28] in 2020, showed a strong correlation between the deltoid tuberosity index (DTI) and the T score value in bone densitometry. Values < 1.4 correlate with low bone mineral density in patients with proximal humerus fracture, and female sex and advanced age were considered independent risk factors for severe proximal humerus fracture.

We are aware of the limitations of the study: the retrospective design, no randomization and no control group, which allows for bias. Finally, as a clinical outcome assessment was not performed, we could not define which of the methods presents the best result and could not extrapolate the results to clinical practice. However, we present the complications and radiographic findings of our study and encourage further investigation.

In this study, which presented homogeneous samples in both groups, no significant difference was found regarding the rate of complications and surgical reapproach. However, the nail group had two serious complications (screw cut-out with secondary varus deviation) requiring surgical reapproach.

CONCLUSION

Regarding the number of complications in 2- and 3-part proximal humerus fractures, there was no significant difference in the treatment between plate and antegrade nailing. The nail group showed less residual varus loss in the postoperative period, however, there were two serious complications with screw cut-out in that group. Despite the short follow-up, this study is in agreement with current results published in the medical literature. New studies, with a larger sample, randomization and longer follow-up time are needed to define the best treatment option for 2- and 3-part proximal humerus fractures.

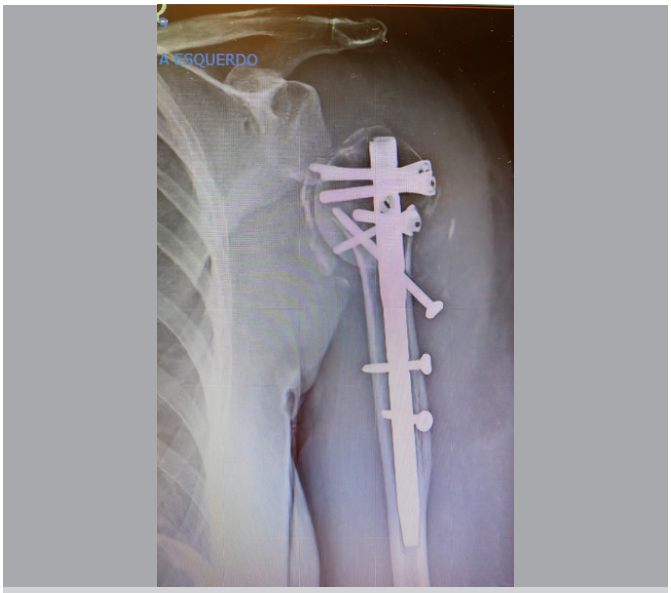

Figure 4. Cut-out with loss of varus reduction with intramedullary nail.

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REFERENCES

1. Kleinlugtenbelt YV, Bhandari M. Cochrane in CORR®: interventions for treating proximal humeral fractures in adults (review). Clin Orthop Relat Res. 2015;473(9):2750-6.
2. Wong J, Newman JM, Gruson KI. Outcomes of intramedullary nailing for acute proximal humerus fractures: a systematic review. J Orthop Traumatol. 2016;17(2):113-22.
3. Launonen AP, Lepola V, Saranko A, Flinkkilä T, Laitinen M, Mattila VM. Epidemiology of proximal humerus fractures. Arch Osteoporos. 2015;10(1):209.
4. Cruickshank D, Lefaivre KA, Johal H, MacIntyre NJ, Sprague AS, Scott T, et al. A scoping review of biomechanical testing for proximal humerus fracture implants. BMC Musculoskelet Disord. 2015;16:175.
5. Antonios T, Bakti N, Nzeako O, Mohanlal P, Singh B. Outcomes following fixation for proximal humeral fractures. J Clin Orthop Trauma. 2019;10(3):468-73.
6. Boesmueller S, Wech M, Gregori M, Domaszewski F, Bukaty A, Fialka C, Albrecht C. Risk factors for humeral head necrosis and non-union after plating in proximal humeral fractures. Injury. 2016;47(2):350-5.
7. Chow RM, Begum F, Beaupre LA, Carey JP, Adeeb S, Bouliane MJ. Proximal humeral fracture fixation: locking plate construct ± intramedullary fibular allograft. J Shoulder Elbow Surg. 2012;21(7):894-901.
8. Lópiz Y, García-Coiradas J, García-Fernandez C, Marco F. Proximal humerus nailing: a randomized clinical trial between curvilinear and straight nails. J Shoulder Elbow Surg. 2014;23(3):369-76.
9. Boileau P, Trojani C, Walch G, Krishnan SG, Romeo A, Sinnerton R. Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. J Shoulder Elbow Surg. 2001;10(4):299-308.
10. Neer CS 2nd. Displaced proximal humeral fractures I. Classification and evaluation. J Bone Joint Surg Am. 1970;52(6):1077-89.
11. Spross C, Kaestle N, Benninger E, Fornaro J, Erhardt J, Zdravkovic V, Jost B. Deltoid tuberosity index: a simple radiographic tool to assess local bone quality in proximal humerus fractures. Clin Orthop Relat Res. 2015;473(9):3038-45.
12. Schnetzke M, Bockmeyer J, Porschke F, Studier-Fischer S, Grützner PA, Guehring T. Quality of reduction influences outcome after locked-plate fixation of proximal humeral type-C fractures. J Bone Joint Surg Am. 2016;98(21):1777-85.
13. Fleischhacker E, Siebenbürger G, Helfen T, Gleich J, Böcker W, Ockert B. Varus malposition relates to functional outcomes following open reduction and internal fixation for proximal humeral fractures: a retrospective comparative cohort study with minimum 2 years follow-up. Injury. 2021;52(3):506-10.
14. Capriccioso CE, Zuckerman JD, Egol KA. Initial varus displacement of proximal humerus fractures results in similar function but higher complication rates. Injury. 2016;47(4):909-13.
15. Jaeger M, Leung F, Li W. ORIF – Plate fixation. AO Surgery Reference [Internet]. 2011 [accessed on 2021 Aug 26]. Available from: https://surgeryreference.aofoundation.org/orthopedic-trauma/adult-trauma/proximal-humerus/extraarticular-3-part-surgical-neck-and-tuberosity-no-impaction/orif-plate-fixation#principles
16. Olsson C, Nordqvist A, Petersson CJ. Increased fragility in patients with fracture of the proximal humerus: a case control study. Bone. 2004;34(6):1072-7.
17. Nolan BM, Kippe MA, Wiater JM, Nowinski GP. Surgical treatment of displaced proximal humerus fractures with a short intramedullary nail. J Shoulder Elbow Surg. 2011;20(8):1241-7.
18. Boileau P, d'Ollonne T, Bessière C, Wilson A, Clavert P, Hatzidakis AM, Chelli M. Displaced humeral surgical neck fractures: classification and results of third-generation percutaneous intramedullary nailing. J Shoulder Elbow Surg. 2019;28(2):276-87.
19. Shi X, Liu H, Xing R, Mei W, Zhang L, Ding L, et al. Effect of intramedullary nail and locking plate in the treatment of proximal humerus fracture: an update systematic review and meta-analysis. J Orthop Surg Res. 2019;14(1):285.
20. Li M, Wang Y, Zhang Y, Yang M, Zhang P, Jiang B. Intramedullary nail versus locking plate for treatment of proximal humeral fractures: a meta-analysis based on 1384 individuals. J Int Med Res. 2018;46(11):4363-76.
21. Zhu Y, Lu Y, Shen J, Zhang J, Jiang C. Locking intramedullary nails and locking plates in the treatment of two-part proximal humeral surgical neck fractures: a prospective randomized trial with a minimum of three years of follow-up. J Bone Joint Surg Am. 2011;93(2):159-68.
22. Plath JE, Kerschbaum C, Seebauer T, Holz R, Henderson DJH, Förch S, Mayr E. Locking nail versus locking plate for proximal humeral fracture fixation in an elderly population: a prospective randomised controlled trial. BMC Musculoskelet Disord. 2019;20(1):20.
23. Gracitelli MEC. Estudo randomizado da osteossíntese das fraturas da extremidade proximal do úmero com placa ou haste intramedular [dissertation]. São Paulo: Universidade de São Paulo; 2015.
24. Boileau P, Pennington SD, Alami G. Proximal humeral fractures in younger patients: fixation techniques and arthroplasty. J Shoulder Elbow Surg. 2011;20(2 Suppl):S47-60.
25. Gracitelli MEC, Malavolta EA, Assunção JH, Ferreira Neto AA, Silva JS, Hernandez AJ. Locking intramedullary nails versus locking plates for the treatment of proximal humerus fractures. Expert Rev Med Devices. 2017;14(9):733-9.
26. Wang G, Mao Z, Zhang L, Zhang L, Zhao Y, Yin P, et al. Meta-analysis of locking plate versus intramedullary nail for treatment of proximal humeral fractures. J Orthop Surg Res. 2015;10:122.
27. Sun Q, Ge W, Li G, Wu J, Lu G, Cai M, Li S. Locking plates versus intramedullary nails in the management of displaced proximal humeral fractures: a systematic review and meta-analysis. Int Orthop. 2018;42(3):641-50.
28. Kim DM, Park D, Kim H, Lee ES, Shin MJ, Jeon IH, Koh KH. Risk factors for severe proximal humerus fracture and correlation between deltoid tuberosity index and bone mineral density. Geriatr Orthop Surg Rehabil. 2020;11:2151459320938571.