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Proximal humeral fractures: association between displacement and fatty degeneration of the supraspinatus muscle

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Abstract

Introduction To evaluate the relationship between initial displacement in proximal humeral fractures and fatty degeneration of the rotator cuff measured by CT according to the Goutallier classification.

Material and methods This cross-sectional observational study evaluated patients with proximal humeral fractures over a six-month period. The study included patients ≥ 18 years old with complete radiological views (anteroposterior, lateral, and Grashey) and a CT scan of the affected shoulder; previous fracture or ipsilateral shoulder surgery were excluded. Neer's classification system and Goutallier stages were used to evaluate the patients. Demographic data were collected and, two groups were analysed according to age (≤ 50 years and > 50 years).

Results Sixty-two patients were included (m = 36, f = 26, ratio 1.3:1); seven patients were excluded. Male patients (36, 58.1%), patients older than 50 years (33, 53.2%) and a low-energy injury mechanism (36, 58.1%) were the most frequent cases. According to the Neer system, the most common proximal humerus fracture was fracture-dislocation in 17 (27.4%) cases. The most common stage in Goutallier's classification was I (some fatty streaks) in 22 (35.4%) cases. Younger patients (≤ 50 years) had more displaced fractures with low fatty degeneration ($p = < 0.001$) than older patients (> 50 years), who had minimally displaced fractures with greater fatty degeneration ($p = 0.567$).

Conclusions High-energy mechanisms are associated with younger patients and a more displaced fracture according to the Neer classification. Older patients had a more advanced Goutallier stage and lesser displaced fracture. We should consider a more aggressive approach in the treatment of non-displaced fractures in elderly patients, less conservative and more surgical management, to obtain a better clinical evolution after the treatment of these kinds of fractures.

Level of evidence IV.

Keywords Proximal humeral fractures · Neer classification · Goutallier classification · Fatty degeneration

Introduction

A proximal humerus fracture represents 4% of all fractures commonly observed in adults over 70 years old. These individuals present minimal or non-displaced fractures [1, 2]. The principal injury mechanism is a fall in almost 80% of patients [3]. Several factors are associated with an increased risk or severity of the fracture, including osteoporosis, health status, insulin-dependent diabetes mellitus, and neuromuscular weakness [4, 5].

One of the most used methods for classifying these fractures is the Neer system, which is based on four segments. The four segments are the humeral head, the greater and lesser tuberosity, and the proximal diaphysis. The displacement is 10 mm or 45 degrees of angulation and was originally classified into six groups according to the displacement and the segments involved [6].

The tendon insertions in the greater tuberosity are the supraspinatus, the infraspinatus, and the teres minor. The subscapularis inserts in the minor tuberosity [7]. These four muscles are involved in normal shoulder function. The subscapularis acts as the principal internal rotator and adductor

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while the other three muscles are involved in the external rotation and abduction of the shoulder [7]. Segment displacement occurs by the action of the muscles: the pectoralis major, latissimus dorsi, and teres major pull the humeral shaft medially (adduction), the supraspinatus, infraspinatus, and teres minor send the greater tuberosity in a posterosuperior direction, and the subscapularis acts over the lesser tuberosity with medial displacement. These displacements allow the humeral head to be luxated or twisted through the created defect [7, 8].

One of the main concerns associated with the rotator cuff muscles is fatty degeneration, described and classified by Goutallier et al. [9] They initially observed that a tear in the rotator cuff tendons is followed by muscle degeneration. This classification was originally described with computed tomography (CT) and classified into 5 stages: Stage 0, normal muscle; Stage 1, muscle with some fatty streaks; Stage 2, important fatty infiltration, but there is still more muscle than fat; Stage 3, there is as much fat as muscle; Stage 4, more fat than muscle. These degenerations increase progressively over time and can decrease with successful tendon repair [9]. More recent research has demonstrated that fatty infiltration can occur in the absence of tendon tears [10]. This muscle degeneration can cause minor displacement of fracture fragments and surgical treatment must be changed in a patient with advanced fatty degeneration. A recent study by Hinsley et al., reported a reduced strength in women over 70 years with rotator cuff tears, directly related with the size of the tear. The larger the lesion size was, the greater the reduction in strength was observed in shoulder abduction (small tears 30%; large tears 40% strength reduction) [11].

The main objective of this study was to evaluate the relationship between initial displacement in proximal humeral fractures and fatty degeneration of the rotator cuff measured by CT according to the Goutallier stages. Secondary objectives were to evaluate fatty infiltration according to demographic data. The proposed hypothesis was that proximal humeral fractures with less displacement are associated with greater fatty degeneration.

Materials and methods

This cross-sectional observational study was approved by the Ethics Committee of our institution (registration no. OR22–00006). All patients with proximal humeral fractures treated in our referral trauma center hospital during a six-month period were assessed and included with the following criteria: age $\geq$ 18 years with complete anteroposterior, lateral, and Grashey radiological views, and a CT scan of the affected shoulder. Patients were excluded if they had previous fractures around the shoulder girdle, previous surgical treatment of fractures and/or the rotator cuff or labrum, neurologic disease. The included patients signed written informed consent to participate.

The fractures were evaluated and classified by an upper extremity Orthopaedic surgeon, according to the original Neer [6] system: Group 1, minimally displaced fractures (< 1 cm or less than 45º angulation); Group 2, displacement of the articular segment, anatomical neck; Group 3, shaft displacement, surgical neck; Group 4, greater tuberosity displacement; Group 5, lesser tuberosity displacement; and Group 6, fracture-dislocation. The posterosuperior rotator cuff (supraspinatus) was evaluated and graded according to the original Goutallier classification [9]. Medial parasagittal images were set in the "Y-shaped position" for evaluation.

Demographic data included age, gender, dominant side (left or right), affected side, comorbidities, injury mechanism (low- or high-energy), and the time between injury and CT scan. The criteria for high energy lesions were a fall from a height $\geq$ 3 m, a motor vehicle accident $\geq$ 60 km/h, a motorcycle accident $\geq$ 30 km/h, a motor vehicle accident with a deformity $\geq$ 50 cm; a passenger compartment intrusion $\geq$ 30 cm; or a vehicle rollover. Passenger ejection from the vehicle, a fatality in the same vehicle, a car or motorcycle versus a pedestrian or bicyclist $\geq$ 10 km/h, and a motorcycle or bicycle vs. motorcycle or bicycle or stationary object were also considered [12, 13].

Statistical analysis

Descriptive statistics report the frequency and percentages of quantitative and qualitative variables. Quantitative variables are reported as central tendency measures and dispersion (mean/median, standard deviation/range interquartile). The sample distribution was measured with the Kolmogorov-Smirnov test. Student´s t-test or the Mann–Whitney U test was used to compare two independent groups. One-way ANOVA or the Kruskal-Wallis test was used to compare different groups. The Chi-square test and Fisher's exact test were used to demonstrate an association between qualitative variables. Differences were considered statistically significant with a p-value ≤ 0.05. The statistical analysis was performed with SPSS software version 25 for Windows (IBM Corp., Armonk, NY).

Results

Sixty-nine referred cases were attended in our hospital. Seven (11%) cases were excluded (previous fracture: 4, previous surgical treatment: 2, neurological disease: 1) and 62 (89%) patients were included in this study (male = 36,

female = 26, ratio 1.3:1). Male patients (36, 58.1%) older than 50 years (33, 53.2%) with upper extremity dominance affected (36, 58.1%) and a low-energy injury mechanism (36, 58.1%) were the most frequent cases. A statistically significant difference in sex, age, the absence or presence of comorbidities, and the injury mechanism was observed between younger and older patients ($p < 0.05$). The rest of the demographic data with no statistical differences, are shown in Table 1.

According to the Neer classification system, the most frequent proximal humerus fracture was fracture-dislocation (group 6) in 17 (27.4%) cases, followed by shaft displacement (group 3) in 16 (25.8%) cases. There was a statistically significant difference between younger and older patients. Younger patients had more fracture-dislocation (11 [37.9%] cases) unlike older patients who had minimally displaced fractures in 11 (33.35%) cases ($p = 0.00.1$) (Fig. 1).

In the Goutallier classification, the most frequent stage was I (some fatty streaks) in 22 (35.4%) cases followed by stage II (less fat than muscle) in 19 (30.6%) cases. Younger patients had fewer fatty streaks (18 cases [62.1%]) and older patients had more fat infiltration in the muscle (8 cases [24.2%]) ($p = 0.001$) (Fig. 1). The complete distribution in the Neer classification system and the Goutallier index stage are shown in Table 2.

Goutallier index and fracture displacement

The association between Neer's classification system and the Goutallier index for fatty degeneration was evaluated. We found that patients with good muscle quality (Goutallier index stage I, $n = 22$ [35.5%]) had displaced fractures (Neer group 4 and 6; 17 [77.3%]) in contrast to patients with poor muscular quality (Goutallier stage III or IV, $n = 20$ [33.8%]) who had minimally displaced fractures (Neer group 1, 9 [45%]). These differences were statistically significant ($p = 0.024$). This association was sub-analyzed according to patients age (≤ or > 50 years). Younger patients (≤ 50 years, $n = 29$) had more displaced fractures (Neer group 6, $n = 11$ [37.9%]) with low fatty degeneration (Goutallier stage I or II) ($p = < 0.001$). Older patients ($n = 33$) had minimally displaced fractures (Neer group 1, 11 [33.3%]) with more fatty degeneration (Goutallier stage III or IV) ($p = 0.567$) (Fig. 1). Moreover, 23 (69.9%) of the older patients were women.

Table 1 Demographic characteristics of patients with proximal humeral fracture

Characteristic	Younger $n = 29$ (46.7%)	Older $n = 33$ (53.2%)	Total $N = 62$ (100%)	p-value
Sex, n (%)				< 0.001*†
Male	26 (41.9)	10 (16.1)	36 (58.1)	
Female	3 (4.8)	23 (37.0)	26 (41.9)	
Age (years) x̄ (± SD)	36.8 (± 8.9)	69.9 (± 13.2)	54.4 (± 20.0)	< 0.001*‡
Body Mass Index x̄ (± SD)	25.6 (± 3.5)	26.1 (± 3.5)	25.8 (± 3.5)	0.712 §
Comorbidities, n (%)	4 (6.5)	14 (22.5)	18 (29.1)	-
Diabetes mellitus type 2	2 (3.2)	8 (12.9)	10 (16.1)	
High blood presure	3 (4.8)	9 (14.5)	12 (19.3)	
Osteoporosis	0 (0.0)	1 (1.6)	1 (1.6)	
Other	1 (1.6)	1 (1.6)	2 (3.2)	
Comorbidities, n (%)				0.007*†
Present	4 (6.5)	15 (24.2)	19 (30.6)	
Abscent	25 (40.3)	18 (29)	43 (69.4)	
Dominance, n (%)				0.773†
Dominant	16 (25.8)	17 (27.4)	36 (58.1)	
Non-dominant	13 (20.1)	16 (25.8)	26 (41.9)	
Affected side, n (%)				0.773 †
Right	16 (25.8)	17 (27.4)	36 (58.1)	
Left	13 (20.1)	16 (25.8)	26 (41.9)	
Mechanism of injury, n (%)				< 0.001* †
Low energy	6 (9.6)	28 (45.2)	36 (58.1)	
High energy	23 (37.1)	5 (8.1)	26 (41.9)	
Time between fracture and CT scan (days), median (min-max)	1 (1–4)	1 (1–35)	1 (1–35)	0.819 ‡
Treatment, n (%)				0.438 ll
Conservative	26 (41.9)	31 (50.0)	57 (91.9)	
Surgical	3 (4.8)	2 (3.2)	5 (8.1)	

*$p < 0.05$, † chi square test, ‡ Mann-Whitney U test, § T-test, ll Fisher test

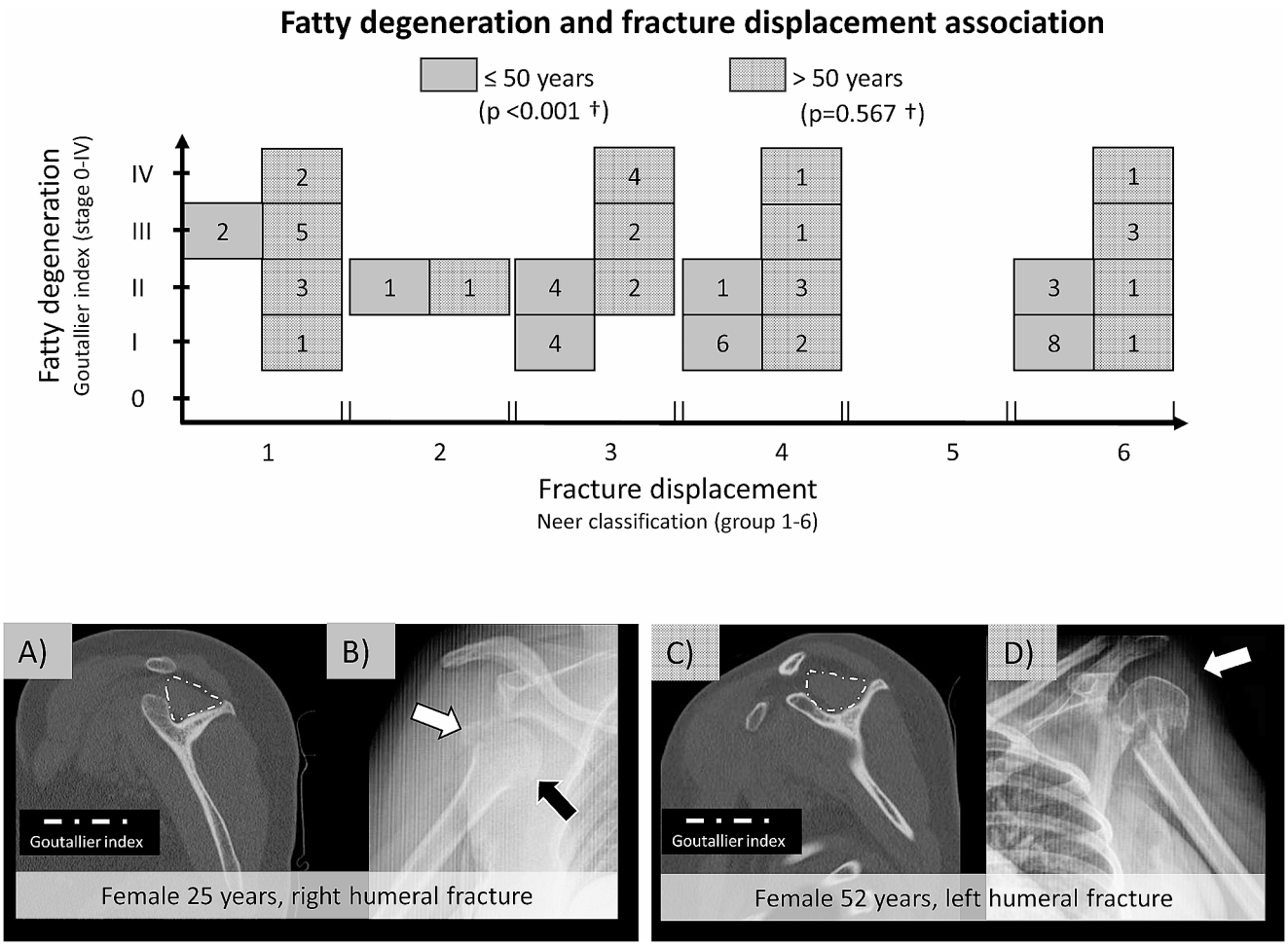

Fig. 1 Fatty degeneration (Goutallier index) and proximal humerus fracture displacement (Neer classification) association between groups (younger [≤ 50 years; dark gray, $n = 29$] or older [> 50 years; light grey, $n = 33$]). Images A and B are of a female 25 years old with right humeral fracture, (**A**) CT scan sagittal view of the supraspinatus muscle (white dotted line triangle) in Goutallier stage I (normal muscle); (**B**) AP shoulder radiography, with Neer grade 6 (fracture-dislocation; white arrow indicates the fracture of the greater tuberosity and the black arrow the dislocation of the humerus). Images C and D are of a female 52 years old with left humeral fracture, (**C**) CT scan sagittal view of the supraspinatus muscle (white dotted line triangle) in Goutallier stage II (important fatty infiltration, but there is still more muscle); (**D**) AP shoulder radiography with Neer grade 1 (minimally displaced fracture, white arrow). *$p < 0.05$, † chi-square test

Goutallier index and dominance

The association between fatty degeneration and upper extremity dominance was analyzed. More than half of the patients had low fatty degeneration (stage I $n = 22$, 35.5%; stage II 19, 30.6%). The dominant side was affected in 22 (35.5%) and the non-dominant side was in 19 (30.6%). There was no statistical difference ($p = 0.255$).

Mechanism of injury and age

A low- or high-energy mechanism of injury and age association was analyzed. High-energy mechanisms were predominant in younger patients (29, 46.7%) in 23 (79.3%) cases. In older patients (33, 53.3%), low energy mechanisms occurred in 28 (84.9%) cases. These differences were statistically significant ($p = 0.001$).

Discussion

Fatty infiltration

Fatty infiltration in the rotator cuff muscles has been studied in relation to the re-tear possibility and to decide the implantation of an anatomic shoulder prosthesis or the use of a reverse shoulder prosthesis. The retear rate in rotator cuff surgery has been directly associated with the Goutallier stage. According to a systematic review by Khair et al. when found an advanced stage (III or IV), it has a greater retear rate in patients even after surgical repair [14]. More

Table 2 Distribution of total patients according Neer's classification system and Goutallier index

Characteristic	Younger $n=29$ (46.7%)	Older $n=33$ (53.2%)	Total $N=62$ (100%)
Neer classification system, Group, n (%)			0.015*‡
1. Minimally displaced	2 (6.8)	11 (33.3)	13 (20.9)
2. Displacement of the articular segment, anatomical neck	1 (3.4)	1 (3.3)	2 (3.2)
3. Shaft displacement, surgical neck	8 (27.5)	8 (24.2)	16 (25.8)
4. Major tuberosity displacement	7 (24.1)	7 (21.2)	14 (22.5)
5. Minor tuberosity displacement	0 (0.0)	0 (0.0)	0 (0.0)
6. Fracture-dislocation	11 (37.9)	6 (18.2)	17 (27.4)
Goutallier index, Stage, n (%)			< 0.001*‡
0. Normal muscle without fat	0 (0.0)	0 (0.0)	0 (0.0)
I. Some fatty streaks	18 (62.1)	4 (12.2)	22 (35.4)
II. More muscle than fat	9 (31.1)	10 (30.3)	19 (30.6)
III. As much muscle as fat	2 (6.8)	11 (33.3)	13 (20.9)
IV. Less muscle than fat	0 (0.0)	8 (24.2)	8 (12.9)

*$p < 0.05$, † chi square test, ‡ Mann-Whitney U test, § T-test, ll Fisher test

recently, this relationship was also observed in the supraspinatus and infraspinatus tendons [15]. Kim et al. reported that smaller retear of the supraspinatus muscle demonstrated a late progression of fatty degeneration in the long term (3 years), while the clinical scores improved over time. They also reported that, larger retears showed an early progression in fatty degeneration with worse clinical scores [16].

A recent report by Matsuki et al. indicated that fatty degeneration could be reversible, at least in part, if the repair of the rotator cuff shows no re-tear even in small and large tears. They also documented that the patients with large tears show greater changes in the improvement of fatty infiltration into the supraspinatus and infraspinatus muscles [17]. Information regarding the evolution of fatty infiltration in patients with proximal humeral fractures is unclear, since this is a parameter that is not usually considered in the evaluation of these injuries.

Fatty infiltration has also been studied after shoulder hemiarthroplasty. Greiner et al. analyzed the correlation between fatty infiltration, the tuberosity position, and clinical outcomes in 20 patients with shoulder hemiarthroplasty; they reported that fatty infiltration of the rotator cuff malposition the tuberosity and causes poorer clinical outcomes [18]. In the current study, it was not possible to identify a rotator cuff tear before the injury. We evaluated fractures, and the initial visit to the emergency room of the patient was for evaluation occur after the injury. Although it is described that the better image study for evaluating a rotator cuff tear is magnetic resonance imaging (MRI) [19], in proximal humeral fractures, a CT scan is the ideal study to complement the evaluation [20].

It would be important to consider the Goutallier stage in patients with proximal humeral fractures even when no previous symptoms (pain or weakness over the affected shoulder) are present. A previous report has shown that muscle atrophy and fatty degeneration occur even in the presence of a tendon with no tear [21]. Moreover, fatty infiltration has been related to age, sex, and the severity of the tear, as well as the number of involved tendons, while muscle atrophy has only been associated with increasing age but not with the severity of the tear [21, 22]. The time frame for moderate fatty infiltration in the supraspinatus muscle is in average three years, while severe fatty infiltration is observed five years after the onset of symptoms [22]. Whereas in the infraspinatus muscle infiltration is slightly more prolonged, moderate fatty infiltration can be seen 3.5 years after the initial symptoms. Severe fatty infiltration has been observed at 5.5 years after the onset of symptoms [23]. A previous report by Panzica et al. measured fatty degeneration of the deltoid muscle related to proximal humeral fractures [24]. Degeneration was measured at three different levels dividing the deltoid into anterior, lateral, and posterior views; they found severe fatty degeneration in the posterior deltoid in 26% of the patients, while a normal muscle stage was found in less than 25% of the patients [24]. In this regard, our study evaluated fatty degeneration in the supraspinatus muscle, which was more severe in patients older than 50 years.

Fracture displacement

The displacement of some of the four principal segments involved in proximal humeral fractures was related to better muscle quality according to the CT scan with the Goutallier index and was not related to the patient´s dominance. Patients older than 50 years had a more advanced stage in the Goutallier index.

The findings in the study made by Klute et al. [21] showed that in non-varus four-part humeral head fractures, the displacement of the greater tuberosity was related to the

fatty degeneration of the posterosuperior rotator cuff, while the varus displaced humeral head fractures, did not show correlation with the condition of the rotator cuff. Our results included all types of proximal humeral fractures, and we found a correlation between the displacement of the fractures and the condition of the rotator cuff. The displaced fractures were observed in patients with a healthier rotator cuff, while non-displaced or minimally displaced fractures were observed in older patients with an advanced stage of fatty degeneration.

In contrast to what is typically described in the literature, where a higher frequency of non-displaced or minimally displaced fractures is reported (49%) [1], our results demonstrated a higher frequency of severe fractures (fracture-dislocation) in 27% of the cases mainly in younger patients associated with a healthier rotator cuff according to Goutallier stages. Our hospital is a referral tertiary trauma center. It is likely that less serious fractures were treated at other institutions.

Limitations

This study had several limitations, one of them being the lack of an MRI to assess rotator cuff integrity and establish a more reliable Goutallier index. The classification of proximal humeral fractures was originally based on the X-ray image, and more recently the CT scan has helped determine the most appropriate treatment option. However, literature reports no obvious difference between the two methods [25, 26]. Another limitation of our study was the lack of follow-up of patients in relation to the final treatment (surgical or conservative) compared with the Goutallier stage. Nevertheless, our main objective was to establish the initial displacement of the fracture.

Implications and significance

The displaced fractures were associated with a healthier rotator cuff (Goutallier index 0–1), while the non-displaced fractures presented more advanced stages of fatty degeneration. We should consider a more aggressive approach in the treatment of non-displaced fractures in elderly patients, less conservative and more surgical management, to obtain a better clinical evolution after the treatment of these kinds of fractures. The Goutallier stage has not been evaluated in previous trials of patients with proximal humeral fracture and it is unclear what is the truly significance of the fatty degeneration in fractures displaced or non-displaced that were treated non-surgical. A comparison of treatment in elderly patients with non-displaced or minimally fractures surgically versus non-surgically evaluating clinical and radiographic follow-up could help to strengthen the above.

Conclusions

Proximal humeral fractures with less displacement are associated with greater fatty degeneration. According to our data, proximal humerus fractures in 50-year-old patients are associated with a low-energy injury mechanism, minimal displacement, and more advanced fatty degeneration of the supraspinatus muscle.

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Declarations

Conflict of interest none.

References

1. Court-Brown CM, Garg A, McQueen MM (2001) The epidemiology of proximal humeral fractures. Acta Orthop Scand 72:365–371. https://doi.org/10.1080/000164701753542023
2. Palvanen M, Kannus P, Niemi S, Parkkari J (2006) Update in the epidemiology of proximal humeral fractures. Clin Orthop Relat Res 442:87–92. https://doi.org/10.1097/01.blo.0000194672.79634.78
3. Lind T, Krøner K, Jensen J (1989) The epidemiology of fractures of the proximal humerus. Arch Orthop Trauma Surg 108:285–287. https://doi.org/10.1007/BF00932316
4. Nevitt MC (1994) Epidemiology of osteoporosis. Clin North Am 20:535–559
5. Kelsey JL, Browner WS, Seeley DG et al (1992) Risk factors for fractures of the distal forearm and proximal humerus. Am J Epidemiol 135:477–489. https://doi.org/10.1093/oxfordjournals.aje.a116314
6. Neer CS 2 (2006) nd. Displaced proximal humeral fractures: part I. Classification and evaluation. 1970. Clin Orthop Relat Res 442:77–82. https://doi.org/10.1097/01.blo.0000198718.91223.ca
7. Iyengar JJ, Ho J, Feeley BT (2011) Evaluation and management of proximal humerus fractures. Phys Sports Med 39:52–61. https://doi.org/10.3810/psm.2011.02.1862
8. Schumaier A, Grawe B (2018) Proximal humerus fractures: evaluation and management in the elderly patient. Geriatr Orthop Surg Rehabil 9. https://doi.org/10.1177/2151458517750516
9. Goutallier D, Postel J, Bernageau J et al (1994) Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clin Orthop Relat Res 78–83
10. Cheung S, Dillon E, Tham SC et al (2011) The presence of fatty infiltration in the infraspinatus: its relation with the condition of the supraspinatus tendon. Arthrosc - J Arthroscopic Relat Surg 27:463–470. https://doi.org/10.1016/j.arthro.2010.09.014
11. Hinsley H, Ganderton C, Arden NK, Carr AJ (2023) Relationship between shoulder abduction strength and rotator cuff tear in elderly women: a general population study. BMJ Open 13. https://doi.org/10.1136/BMJOPEN-2023-071908

12. Ferree S, van der Vliet QMJ, Nawijn F et al (2018) Epidemiology of distal radius fractures in polytrauma patients and the influence of high traumatic energy transfer. Injury 49:630–635. https://doi.org/10.1016/J.INJURY.2018.02.003
13. Briet JP, Houwert RM, Smeeing DPJ et al (2017) Differences in classification between Mono- and Polytrauma and low- and high-energy trauma patients with an ankle fracture: a retrospective cohort study. J Foot Ankle Surg 56:793–796. https://doi.org/10.1053/j.jfas.2017.04.012
14. Khair MM, Lehman J, Tsouris N, Gulotta LV (2016) A systematic review of preoperative fatty infiltration and rotator cuff outcomes. HSS J 12:170–176. https://doi.org/10.1007/s11420-015-9465-5
15. Tsuchiya S, Bois AJ, Matthewson G et al (2023) The relationship between preoperative Goutallier stage and retear rates following posterosuperior rotator cuff repair: a systematic review. J Shoulder Elb Surg 32:435–443. https://doi.org/10.1016/j.jse.2022.09.011
16. Kim JH, Min YK, Jang YC, Seo WS (2024) Serial changes of fatty degeneration and clinical outcomes after repair of medium-sized rotator cuff tears. Clin Orthop Surg 16:95. https://doi.org/10.4055/CIOS23146
17. Matsuki K, Sugaya H, Takahashi N et al (2024) Fatty degeneration of the rotator cuff muscles improves in shoulders with successful arthroscopic rotator cuff repair: a prospective study using quantitative T2 mapping techniques, with 2-Year follow-up. JBJS Open Access 9. https://doi.org/10.2106/JBJS.OA.23.00083
18. Greiner SH, Diederichs G, Kröning I et al (2009) Tuberosity position correlates with fatty infiltration of the rotator cuff after hemiarthroplasty for proximal humeral fractures. J Shoulder Elb Surg 18:431–436. https://doi.org/10.1016/j.jse.2008.10.007
19. McCrum E (2020) MR Imaging of the Rotator Cuff. Magn Reson Imaging Clin N Am 28:165–179. https://doi.org/10.1016/J.MRIC.2019.12.002
20. Robinson BC, Athwal GS, Sanchez-Sotelo J, Rispoli DM (2008) Classification and imaging of proximal humerus fractures. Orthop Clin North Am 39:393–403. https://doi.org/10.1016/J.OCL.2008.05.002
21. Barry JJ, Lansdown DA, Cheung S et al (2013) The relationship between tear severity, fatty infiltration, and muscle atrophy in the supraspinatus. J Shoulder Elb Surg 22:18–25. https://doi.org/10.1016/j.jse.2011.12.014
22. Melis B, Defranco MJ, Chuinard C, Walch G (2010) Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. Clin Orthop Relat Res 468:1498–1505. https://doi.org/10.1007/s11999-009-1207-x
23. Melis B, Wall B, Walch G (2010) Natural history of infraspinatus fatty infiltration in rotator cuff tears. J Shoulder Elb Surg 19:757–763. https://doi.org/10.1016/j.jse.2009.12.002
24. Panzica M, Brandes J, Schmiddem U et al (2017) Fatty degeneration of the deltoid muscle associated with displaced proximal humerus fractures. Technol Health Care 25:959–967. https://doi.org/10.3233/THC-170834
25. Fuchs B, Weishaupt D, Zanetti M et al (1999) Fatty degeneration of the muscles of the rotator cuff: Assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elb Surg 8:599–605. https://doi.org/10.1016/S1058-2746(99)90097-6
26. Schaefer O, Winterer J, Lohrmann C et al (2002) Magnetic resonance imaging for supraspinatus muscle atrophy after cuff repair. Clin Orthop Relat Res 403:93–99. https://doi.org/10.1097/00003086-200210000-00015