Accepted Manuscript

Title: Radiographic patterns of osteoporotic proximal humerus fractures

Authors: Stefano Carbone, Riccardo Mezzoprete, Matteo Papalia, Valerio Arceri, Andrea Carbone, Stefano Gumina

PII: S0720-048X(17)30547-8
DOI: https://doi.org/10.1016/j.ejrad.2017.12.025
Reference: EURR 8053

To appear in: *European Journal of Radiology*

Received date: 26-3-2017
Revised date: 1-11-2017
Accepted date: 31-12-2017

Please cite this article as: Carbone Stefano, Mezzoprete Riccardo, Papalia Matteo, Arceri Valerio, Carbone Andrea, Gumina Stefano.Radiographic patterns of osteoporotic proximal humerus fractures.*European Journal of Radiology* https://doi.org/10.1016/j.ejrad.2017.12.025

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

ACCEPTED MANUSCRIPT

Radiographic patterns of osteoporotic proximal humerus fractures

Running title: Osteoporotic proximal humerus fractures

Stefano Carbone (MD, PhD)*,**, Riccardo Mezzoprete (MD)*, Matteo Papalia (MD)***, Valerio Arceri (MD)*, Andrea Carbone (MD)**, Stefano Gumina (MD, PhD)****.

*: Ospedale San Camillo de Lellis, Dept. Of Orthopaedics and Traumatology. Rieti, Italy.

**: Sapienza University of Rome, Rome, Italy.

***: Clinica Nuova Itor, Dept. Of Orthopaedics and Traumatology. Rome, Italy.

****: Section of Orthopaedics and Traumatology, Shoulder and Elbow Unit, Sapienza University, Rome, Italy.

Corresponding author:

Stefano Carbone

Via Giulio Pittarelli 114, 00166. Rome, Italy.

stefcarbone@yahoo.it

Phone number: +393496092317

Fax number: +396631881

No support and disclaimer to declare.

IRB: In light of the Italian law, the authors are not required to have this type of study approved. However, each author certifies that his institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

ABSTRACT

Objective: The objectives of the study were: a) to identify osteoporotic proximal humerus fractures in a large consecutive series of patients; b) to identify radiographic fracture patterns among osteoporotic and non-osteoporotic proximal humerus fractures; and c) to calculate intra- and inter-observer reliability of assessment of osteoporosis and of radiographic fracture patterns.

Methods: This was a prospective observational study of patients admitted to the emergency department affected by a proximal humerus fracture between June 2014 and June 2016. Three researchers evaluated demographic data and comorbidities, x-rays and CT-scans. A new evaluation

ACCEPTED MANUSCRIPT

method for assessment of osteoporosis was proposed; 7 radiographic fracture patterns were studied. Reliabilities between intra- and inter-tester evaluations, and correlations between the presence of osteoporosis and the 7 radiologic fracture patterns were calculated .

Results: Two hundred twenty-five patients with a humeral fracture were recruited. Their mean (26-95, 32) age was 58.Of those, 163 (72.4%) were identified as osteoporotic. Among the three raters, the intra- and inter-observer agreement using the proposed methods were high or excellent. Significant correlations with diagnosis of osteoporosis were found with Codman-Lego type 12(p=0.041), metaphyseal comminution(p<0.001), impaction of fragments(p=0.023), comminution of tuberosities(p=0.037), inferior subluxation(p=0.029). Intra- and inter-tester reliability of evaluation of these osteoporotic fracture patterns were high.

Conclusions: Osteoporosis of the proximal humerus was identified in 72% of patients during a two year period; most of these patients were elderly females sustaining low energy trauma. These fractures showed to have specific radiographic patterns, as comminution of metaphysis and tuberosities, impaction of fragments, and inferior subluxation of the humeral head. These patterns can be assessed with the simple observation of a 2-plan view of a radiograph, without the use of specific software.

Level of evidence: Level III, observational study.

Keywords: proximal humerus fractures; osteoporosis; fracture impaction and comminution; inferior subluxation; bone mineral densisty; radiographic patterns

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

INTRODUCTION

Osteoporosis is an underestimated aspect of fractures of the proximal humerus, although it is known that these fractures occur in osteoporotic bone and the incidence is on rise[1,2] Osteoporosis affects the pathogenesis, with an high risk of sustaining a fracture after low energy trauma, and the treatment, because of the inability to achieve a stable fixation in the weak and brittle osteoporotic bone[3]. Biomechanical studies published on osteoporosis of the proximal humerus have shown that screws have a minimal purchase in the osteoporotic bone[4,5], with consequent failure of fixation and screw penetration of articular surface[6]. Surprisingly, assessment of osteoporosis or bone loss was not provided in any of the historical classifications, such as those by Neer[7] and AO[8]. Moreover, because of the aging of general population, these fractures have a very high clinical and economic impact on the health system. In fact, while in the 90's these fractures were reported to be less frequent than in the hip and wrist[9,10], in 2011 Calvo and colleagues reported that nondisplaced proximal humeral fractures were among the most common fractures associated with osteoporosis.[11] Because of the lack of assessment of osteoporosis in fractures of the proximal humerus, some authors have proposed the following methods. In 2003, Tingart et al. studied the cortical thickness of the proximal humeral diaphysis and they found it may predict bone mineral density of the proximal humerus.[12] More recently, Mather et al. identified the negative predictive value of average cortical bone thickness of the proximal humerus in ruling out osteoporosis.[13] Finally, Spross et al. investigated the deltoid tuberosity index as a simple radiographic tool to assess local bone quality in proximal humerus fractures[14]. At the same time, some authors stated that any fracture caused by low energy trauma, such as a fall from standing position, is considered to be due to osteoporosis[11]. From a literature overview, it emerges that a consensus in definition of proximal humerus osteoporosis is far away to be found. When assessing the bone mineral density (BMD) of the proximal humerus using data from CT scans, Krappinger et al.[15] found that the BMD from pre-operative CT scans may provide a preoperative tool for the assessment of the local bone quality of the proximal humerus. Identification and definition of patterns of osteoporotic

ACCEPTED MANUSCRIPT

proximal humerus fractures have not been clearly assessed in the literature, that is much more focused in treatment of these difficult fractures. Today, there is no description of specific radiographic aspects of these fractures, with only a pragmatic general consensus that osteoporotic fractures are more displaced and comminuted and belong to the elderly [9,10]. Age, gender, associated medical conditions, previous fractures are elements to be considered[3], but this is not enough to define a proximal humerus fracture as osteoporotic. Some efforts have been carried out by Bahrs and colleagues who have highlighted that complexity of proximal humeral fractures was age and gender specific[16], and that most of hospitalized complex fractures were among women older than 60 years old[17].

The hypothesis of this study was that osteoporotic proximal humerus fractures have different radiographic patterns in comparison to the non-osteoporotic fractures, and that assessment of some proposed osteoporotic characteristics may be reliable and reproducible between physicians. Thus, the objectives were: a) to identify osteoporotic proximal humerus fractures in a large consecutive series of patients attending the emergency department with a diagnosis of proximal humerus fracture; b) to study radiographic fracture patterns among osteoporotic and non-osteoporotic proximal humerus fractures; and c) to calculate among the three raters the intra- and inter-observer reliability of assessment of osteoporosis and of patterns of osteoporotic proximal humerus fractures.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

MATERIALS AND METHODS

This is a prospective observational study of patients who were admitted to the emergency department with a diagnosis of proximal humerus fracture between June 2014 and June 2016. All subjects signed informed consent, and were extensively informed about the purpose of the study. All rights of the enrolled subjects in the present study were protected. The study was carried out in accordance with the World Medical Association Declaration of Helsinki. The local ethic committee gave the approval to the study (Ospedale San Camillo de Lellis, Rieti, Italy n. 2014/19).

In the emergency department, patients with clinical signs of shoulder girdle fracture underwent to standard x-ray examination with a true perpendicular anteroposterior, transthoracic, Y (scapular plane) and axillary (when possible) radiographs of the involved shoulder. If a fracture of the proximal humerus was noted or suspected in any the radiographs, a CT exam of both shoulders with three-dimensional (3D) reconstruction was requested. As previously stated in the literature, scanning the contralateral uninjured side increases neither the radiation dose nor the time for the CT scan [15]. Patients characteristics such as age, gender, medical comorbidities (diabetes, alcohol and nicotine abuse, previous diagnosis of osteoporosis), height (cm), weight (kg), body mass index (BMI) and accident type (high energy trauma such as sports accidents, road traffic accidents, falls from heights >2 m; low energy trauma when walking, stumbling, syncopal) were recorded for study purposes.

First phase of the study: osteoporosis assessment

X-rays and CT scans were examined on diagnostic quality liquid crystal display monitors using Digital Imaging and Communication in Medicine compliant grading software (IMPAX Web 1000; Agfa, Mortsel, Belgium). Measurements were done electronically with the length-measuring tool provided by IMPAX™.

The two-plane radiographs were initially evaluated by one radiologist and one orthopedic surgeon in the emergency department; if a fracture of the proximal humerus was noted, a CT-scan was

ACCEPTED MANUSCRIPT

obtained. Two copies of each patient's folder were given to three orthopedic surgeons differently skilled in shoulder trauma surgery (the first assessor was the chief of traumatology department, the second and third were assistant to shoulder and elbow trauma; each of them had a three year fellowship in shoulder and elbow surgery). Using the first copy of the folder within four weeks after the patient's fracture, the three researchers assessed osteoporosis of the proximal humerus using one radiologic, one CT and two patient's dichotomous parameters. These measurements were blinded. The radiologic parameter (measured on a true perpendicular anteroposterior radiograph with 1.2-m distance of X-ray source from the shoulder with a beam magnification of 10 %) was Average Cortical Bone Thickness (CBTAVG) lower than 6 mm [13], with this ratio measured at the most proximal point on the humerus where the outer medial and lateral cortical borders become parallel, and 20 mm distal to this level. The CT parameter consisted of calculation of local (in the uninjured humerus) BMD using the method proposed by Krappinger et al. [15], with a value lower than 90 mg/cm3 arbitrarily determined for identifying local osteoporosis (PACS software J-Vision 3.3.16, Tiani Medgraph, Brunn am Gebirge, Austria) [15]. The two dichotomous parameters for each patient were history of a low energy trauma (YES/NO)(fall from standing position) [11] and a previous diagnosis of osteoporosis (YES/NO, using dual-energy x-ray absorptiometry, DEXA). To be included in the osteoporotic group, both the radiologic and CT parameters and at least one of the two dichotomous variables had to be present. The intra- and inter-observer reliability of osteoporosis assessment with this three-level method was then calculated.

Second phase of the study: evaluation of radiographic fracture patterns

The second step consisted of an evaluation of radiographic fracture patterns, with the second copy of the folder; this was done twice (one week of intermission) by each of the three researchers, after completing the assessment of osteoporosis (first phase). To avoid any bias or confounding factor, the results of the first phase were blinded to the raters. The evaluation was done on radiographs and/or CT images, depending on the surgeon's preference. The researchers considered:

1. Binary fracture description based on Codman-Lego system; [18]

ACCEPTED MANUSCRIPT

2. Length of the postero-medial metaphyseal head extension (< or >8 mm); [18]
3. Integrity of the medial hinge (Disrupted Yes/No); [18]
4. Comminution of metaphysis (Is there any comminution of proximal humerus metaphysis? Yes/No) (Fig.1);
5. Impaction of fracture segments (Is any part of the head or metaphysis impacted into the shaft? Yes/No) (Fig.2); [19]
6. Comminution of tuberosities (Is there any comminution of greater or lesser tuberosity? Yes/No) (Fig.3);
7. Humeral head inferior subluxation (Is there an inferior displacement of the head respect to the glenoid inferior edge greater than 1 cm? Yes/No) (Fig.4).

The first three characteristics were considered because because they have previously been reported in a study on osteoporotis of the proximal humerus [3]; the fourth and fifth characteristics were included because recently identified and described in osteoporotic fractures [19,20,21]; the last two because they have been observed by the authors among osteoporotic fractures. The intra- and inter-observer reliability of evaluation of the proposed osteoporotic radiographic characteristics were then calculated.

Statistical analysis

An independent investigator collected the data, and the statistical analysis was then performed using SPSS software, version 16.0 (SPSS, Chicago, IL).

The intra- and interobserver reliabilities of the radiologic (CBTAVG) and CT scan BMD measurements were estimated with intraclass correlation coefficients (ICC) (ICC Model 2 for intraobserver and ICC Model 2k for interobserver variability). For categorical variables, the intra- and inter-observer agreements were determined using the κ statistic, with the level of significance set a priori at $P < .01$. Interpretation of the κ statistic was performed as described by Landis and Koch in 1977. Agreement was considered excellent if κ fell between 0.81 and

ACCEPTED MANUSCRIPT

1.0, high if κ was between 0.61 and 0.80, moderate if κ was 0.41 to 0.60, fair if κ was 0.21 to 0.40, and poor if κ was 0.20 or less [22].

Correlations of the 7 radiologic characteristics in the osteoporotic and non-osteoporotic group were calculated with multivariate linear regression model, as well as between patient's characteristics and osteoporosis. Correlation of humeral head inferior subluxation with BMI was studied with the same method. Correlations for metric scaled data were quantified using the Pearson coefficient.

Categorical data were reported as percentages and numbers of observations of total.

P-values <0.05 were considered to be statistically significant.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

RESULTS

During the recruitment phase, 256 patients were admitted to the emergency room and received proximal humerus fracture as main diagnose. Of these, 20 were not considered for study purposes because some demographic data were missing, 5 because they were affected by a bilateral fracture and a further 6 patients were excluded because because their CT scans were missing. 225 patients who were affected by unilateral proximal humerus fracture were available. Using the three-level evaluation method, 163/225 (72.4%) fractures were identified as osteoporotic, leaving 62/225 (27.5%) as non-osteoporotic. The intraobserver reliability was high and not different between the CBTAVG (ICC = 0.77 and 0.83) and BMD (ICC = 0.81 and 0.82). However, the interobserver reliability was higher for the CBTAVG (ICC = 0.94; 95% CI, 0.93–0.96) than for the BMD (ICC = 0.83; 95% CI, 0.70–0.90). The intra-observer agreements of the categorical variables ranged between 0.77 and 0.84 (mean 0.83, excellent); the inter-observer agreements between 0.73 and 0.88 (mean 0.82, excellent).

Table 1 summarizes the results of patients' age, sex, medical comorbidities, height, weight, BMI and accident type in the whole study group, and for both patient subgroups.

Table 2 summarizes the results of the 7 characteristics that were evaluated in the whole study group, and for both patient subgroups. The intra- and inter-observer reliabilities of the 7 proposed osteoporotic characteristics were, respectively: 1) Codman-Lego, 0.79 (95% CI: 0.7-0.9) and 0.76 (95% CI: 0.63-0.79); 2) Length of metaphyseal extension, 0.71 (95% CI: 0.52-0.88) and 0.66 (95% CI: 0.6-0.71) ; 3) Integrity of medial hinge, 0.69 (95% CI: 0.6-0.78) and 0.65 (95% CI: 0.53-0.73); 4) Comminution of metaphysis, 0.88 (95% CI: 0.81-0.95) and 0.85 (95% CI: 0.82-0.87; 5) Impaction of fracture segments, 0.73 (95% CI: 0.71-0.77) and 0.77 (95% CI: 0.73-0.85; 6) Comminution of the tuberosities, 0.85 (95% CI: 0.79-0.96) and 0.84 (95% CI: 0.79-0.89; 7) Inferior subluxation, 0.75 (95% CI: 0.68-0.9) and 0.69 (95% CI: 0.63-0.72).

Diagnosis of osteoporosis was associated with older age (p=0.012) and female sex (p=0.02); previous diagnosis of osteoporosis (p=0.034); low energy trauma (p=0.04). Significant correlations

ACCEPTED MANUSCRIPT

between diagnosis of osteoporosis were found with: Codman-Lego type 12 ($p=0.041$), metaphyseal comminution ($p<0.001$), impaction of fragments ($p=0.023$), comminution of tuberosities ($p=0.037$), inferior subluxation ($p=0.029$). Table 3 summarizes correlations between diagnosis of osteoporosis and the 7 radiographic patterns. Humeral head inferior subluxation was significantly associated with a BMI of over 30 ($p=0.019$). Of the 77 patients with a BMI of over 30, 50/77 (%) showed subluxation (50/77, 65%); of these 50, 43 (86%) were female.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

DISCUSSION

The primary purposes of this study were to characterize osteoporotic fractures in a large consecutive series of patients affected by a proximal humerus fracture and to describe radiographic patterns of osteoporotic proximal humerus fractures. The secondary purposes were to calculate intra- and inter-observer reliabilities of assessments of the local osteoporosis and of the radiographic fracture patterns.

Following the reported methods, three surgeons found an osteoporotic proximal humerus fracture in 72.4% of a two-year survey population. The osteoporotic proximal humerus fractures showed to have specific radiographic patterns as metaphyseal comminution, impaction of fragments, comminution of tuberosities and inferior subluxation. Further, we found an high intra- and inter-observer reliability of assessments; consequently, diagnosis of osteoporosis and identification of radiographic patterns with the proposed methods appeared reliable and reproducible. With a simple but systematic observation method of x-rays or CT-exams, the surgeon can be able to identify an osteoporotic fracture both by the bone quality (CBTAVG and BMD) and by some particular patterns of the fracture lines. We can consider a fracture of the proximal humerus as osteoporotic if the osteoporotic characteristics (metaphyseal comminution, impaction of fragments, comminution of tuberosities and inferior subluxation) are assessed. Until today, in clinical practice, we have accepted the general concept that fractures in elderly with probable osteoporosis are more prone to displacement and comminution, but there are no published articles and no specific analysis of fractures characteristics. In 2 previous studies [20,21], Carbone et al. initially observed that metaphyseal comminution and impaction of the head affect the clinical outcome of osteoporotic fractures. The findings of this study included a description of osteoporotic proximal humerus fractures with 7 specific characteristics. In young patient, however, comminution could be either due to high-energy trauma or osteoporosis and so, comminution cannot be considered as hallmark of osteoporosis.

ACCEPTED MANUSCRIPT

Our results are in line with previous reports affirming that simple-to-measure radiographic parameters of the proximal humerus are more useful in predicting ultimate fracture load than sophisticated exams and evaluations such as DEXA density.[23] Combining our results with those of this article, we speculate that DEXA evaluations are not necessary for the diagnosis of osteoporosis of proximal humerus fractures.

As for the proximal femur, osteoporosis importantly affects the outcome of fixation. In recent years, in front of alarming percentage of complications as humeral head articular surface perforation by screws with percentage up to 73 % of cases [6], authors from different countries of the world focused their attention on conservative treatment also for complex displaced fractures [24-26]. These authors stated that results do not support the increased use of surgery for patients with displaced fractures of the proximal humerus. Some other authors, however, have tried to improve the strength of fixation by the use of augmentation, such as fibular strut graft [27], calcium phosphate cement [28], endosteal cage [29]. The aim of this study was to help the surgeon to identify osteoporotic fractures using specific and simple radiographic criteria, so the treatment of these difficult fractures goes beyond the study purposes. In the osteoporotic bone, fixation should be planned considering 5-7 mm impaction of fragments [20,21]. Accordingly, surgeons treating proximal humerus fractures should not place screws or pins in the subchondral bone, because of possible perforation of the humeral head.

A simple model proposed to describe a proximal humerus fracture is an empty egg-shell [3]. When the egg-shell breaks down, the result is comminution and impaction of the shell. The same holds for an empty osteoporotic humeral head and its tuberosities: comminution of metaphysis and tuberosities, and impaction of fragments. In addition, because of older age and female sex with possible muscular atrophy and obesity (BMI>30) that were frequently observed in this population, an inferior subluxation of the head may be noted. This was confirmed by a significant correlation between BMI higher than 30 and assessment of inferior subluxation. The significance of inferior

ACCEPTED MANUSCRIPT

subluxation that often alarms the radiologists is only partially known [30] and further studies should clarify if this is an asymptomatic momentary condition or not.

This study has some limitations. Because the main purpose was to help the surgeon to identify osteoporotic proximal humerus fractures, the treatment was not considered; so, we can only argue that the treatment method for these fractures should be different from the non-osteoporotic, and it remains an important and unresolved point of discussion. Fixation should be planned considering 5-7 mm impaction of fragments. Another possible limitation is that fracture images were studied by surgeons with different skill in shoulder trauma, and so the results may not be reproducible in the general orthopedic and radiologist community. At the same time, assessments of average cortical bone thickness (CBTAVG) on x-rays and local bone mineral densisty (BMD) using CT data may not be easy to perform, especially in the emergency department and/or in absence of software such as IMPAX^{TM}. Thus, we propose the simple observation of specific radiographic fracture patterns on an antero-posterior radiograph to overcome this problem.

CONCLUSION

Osteoporosis of the proximal humerus was identified in 72% of a two-year survey population group using a simple and reliable method; fracture were seen among elderly sustaining low energy trauma. These fractures have specific radiographic patterns, as comminution of metaphysis and of tuberosities, impaction of fragments, and inferior subluxation of the humeral head. These characteristics can be assessed with the simple observation of a 2-plane radiograph, without any specific software.

Conflicts of interest: None.

ACCEPTED MANUSCRIPT

References

[1] Kim SH, Szabo RM, Marder RA. Epidemiology of humerus fractures in the United States: nationwide emergency department sample, 2008. Arthritis Care Res (Hoboken) 2012;64:407-414. doi: 10.1002/acr.21563.

[2] Palvanen M, Kannus P, Niemi S, Parkkari J. Update in the epidemiology of proximal humeral fractures. Clin Orthop Relat Res. 2006;442:87-92.

[3] Hertel R. Fractures of the proximal humerus in osteoporotic bone. Osteoporos Int 2005; 16:65–72. DOI: 10.1007/s00198-004-1714-2

[4] Seebeck J, Goldhahn J, Stadele H, Messmer P, Morlock MM, Schneider E. Effect of cortical thickness and cancellous bone density on the holding strength of internal fixator screws. J Orthop Res 2004; 22:1237–1242. DOI: 10.1016/j.orthres.2004.04.001

[5] Seebeck J, Goldhahn J, Morlock MM, Schneider E. Mechanical behavior of screws in normal and osteoporotic bone. Osteoporos Int 2005; 16:107–111. DOI: 10.1007/s00198-004-1777-0

[6] Jost B, Spross C, Grehn H, Gerber C. Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome. J Shoulder Elbow Surg 2013; 22:542-549. DOI: 10.1016/j.jse.2012.06.008.

[7] Neer CS, 2nd Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am 1970; 52:1077–1089

[8] Muller M, Nazarian S, Koch P, Schatzker J. The Comprehensive Classification of Fractures in Long Bones. Berlin: Springer-Verlag, 1990.

[9] Lauritzen JB, Schwarz P, Lund B, McNair P, Transbol I. Changing incidence and residual lifetime risk of common osteoporosis-related fractures. Osteoporos Int1993; 3:127–132

ACCEPTED MANUSCRIPT

[10] Seeley DG, Browner WS, Nevitt MC, Genant HK, Scott JC, Cummings SR. Which fractures are associated with low appendicular bone mass in elderly women? The study of osteoporotic fractures research group. Ann Intern Med 1991; 115:837–842

[11] Calvo E, Morcillo D, Foruria AM, Redondo-Santamaría E, Osorio-Picorne F, Caeiro JR; GEIOS-SECOT Outpatient Osteoporotic Fracture Study Group. Nondisplaced proximal humeral fractures: high incidence among outpatient-treated osteoporotic fractures and severe impact on upper extremity function and patient subjective health perception. J Shoulder Elbow Surg 2011; 20:795-801. doi: 10.1016/j.jse.2010.09.008.

[12] Tingart MJ, Apreleva M, von Stechow D, Zurakowski D, Warner JJ. The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. J Bone Joint Surg Br 2003; 85:611-617. DOI: 10.1302/0301-620X.85B4.12843

[13] Mather J, MacDermid JC, Faber KJ, Athwal GS. Proximal humerus cortical bone thickness correlates with bone mineral density and can clinically rule out osteoporosis. J Shoulder Elbow Surg 2013; 22:732-738. DOI: 10.1016/j.jse.2012.08.018.

[14] 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; 473:3038-3045. DOI: 10.1007/s11999-015-4322-x.

[15] Krappinger D, Roth T, Gschwentner M, Suckert A, Blauth M, Hengg C, et al. Preoperative assessment of the cancellous bone mineral density of the proximal humerus using CT data. Skeletal Radiol 2012; 41:299-304. DOI: 10.1007/s00256-011-1174-7

[16] Bahrs C, Bauer M, Blumenstock G, Eingartner C, Bahrs SD, Tepass A, Weise K, Rolauffs B. The complexity of proximal humeral fractures is age and gender specific. J Orthop Sci 2013;18:465-470. DOI: 10.1007/s00776-013-0361-x.

ACCEPTED MANUSCRIPT

[17] Bahrs C, Stojicevic T, Blumenstock G, Brorson S, Badke A, Stöckle U, Rolauffs B, Freude T. Trends in epidemiology and patho-
atomical pattern of proximal humeral fractures. Int Orthop 2014; 38:1697-1704. DOI: 10.1007/s00264-014-2362-6.

[18] Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg 2004; 13:427-33. DOI: 10.1016/j.jse.2004.01.034

[19] Resch H. Proximal humeral fractures: current controversies. J Shoulder Elbow Surg 2011; 20:827-832. DOI: doi: 10.1016/j.jse.2011.01.009.

[20] Carbone S, Moroder P, Arceri V, Postacchini R, Gumina S. The amount of humeral head impaction of proximal humeral fractures fixed with the Humerusblock® device. Int Orthop 2014; 38:1451–1459. DOI: 10.1007/s00264-014-2327-9

[21] Carbone S, Papalia M. The amount of impaction and loss of reduction in osteoporotic proximal humeral fractures after surgical fixation. Osteoporos Int 2016; 27:627-633. DOI: 10.1007/s00198-015-3304-x.

[22] Landis JR, Koch GC. The measurement of observer agreement for categorical data. Biometrics 1977; 33: 159-174.

[23] Skedros JG, Mears CS, Burkhead WZ. Ultimate fracture load of cadaver proximal humeri correlates more strongly with mean combined cortical thickness than with areal cortical index, DEXA density, or canal-to-calcar ratio. Bone Joint Res. 2017;6:1-7. DOI: 10.1302/2046-3758.61.BJR-2016-0145.R1.

[24] Dean BJ, Jones LD, Palmer AJ, Macnair RD, Brewer PE, Jayadev C, Wheelton AN, Ball DE, Nandra RS, Aujla RS, Sykes AE, Carr AJ. A review of current surgical practice in the operative treatment of proximal humeral fractures: Does the PROFHER trial demonstrate a need for change? Bone Joint Res 2016; 5:178-184. DOI: 10.1302/2046-3758.55.2000596.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

[25] Handoll HH, Ollivere BJ, Rollins KE. Interventions for treating proximal humeral fractures in adults. Cochrane Database Syst Rev 2012; 12:CD000434. DOI: 10.1002/14651858.CD000434.pub3

[26] Rangan A, Handoll H, Brealey S, et al. PROFHER Trial Collaborators. Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. JAMA 2015; 313:1037–1047. DOI: 10.1001/jama.2015.1629.

[27] Saltzman BM, Erickson BJ, Harris JD, Gupta AK, Mighell M, Romeo AA. Fibular Strut Graft Augmentation for Open Reduction and Internal Fixation of Proximal Humerus Fractures: A Systematic Review and the Authors' Preferred Surgical Technique. Orthop J Sports Med 2016 ;21; 4:2325967116656829. DOI: 10.1177/2325967116656829.

[28] Egol KA, Sugi MT, Ong CC, Montero N, Davidovitch R, Zuckerman JD. Fracture site augmentation with calcium phosphate cement reduces screw penetration after open reduction-internal fixation of proximal humeral fractures. J Shoulder Elbow Surg 2012; 21:741-748. DOI: 10.1016/j.jse.2011.09.017.

[29] Russo R, Cautiero F, Ciccarelli M, Vernaglia Lombardi L. Reconstruction of unstable, complex proximal humeral fractures with the da Vinci cage: surgical technique and outcome at 2 to 6 years. J Shoulder Elbow Surg 2013; 22:422-31. DOI: 10.1016/j.jse.2012.04.010.

[30] Pritchett J. Inferior subluxation of the humeral head after trauma or surgery. J Shoulder Elbow Surg 1997; 6:356-359.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Figure legends

Fig. 1a,b Comminution of metaphysis: Immediate post-fracture x-ray with comminution of metaphysis (a); ten-day follow-up x-ray showing severe displacement (b).

Fig. 2a,b,c Impaction of fracture segments. Antero-posterior view(a), CT coronal view (b) and 3-D reconstruction (c) of a varus impacted fracture.

Fig. 3a,b,c Comminution of tuberosities. Antero-posterior view(a), CT coronal view (b) and 3-D reconstruction (c) of a Codman-Lego type 12 fracture showing severe comminution of tuberosisties.

Fig. 4a,b Humeral head inferior subluxation. Antero-posterior view (a) and CT coronal view (b) of a Codman-Lego type 7 fracture showing inferior subluxation of the humeral head.

ACCEPTED MANUSCRIPT

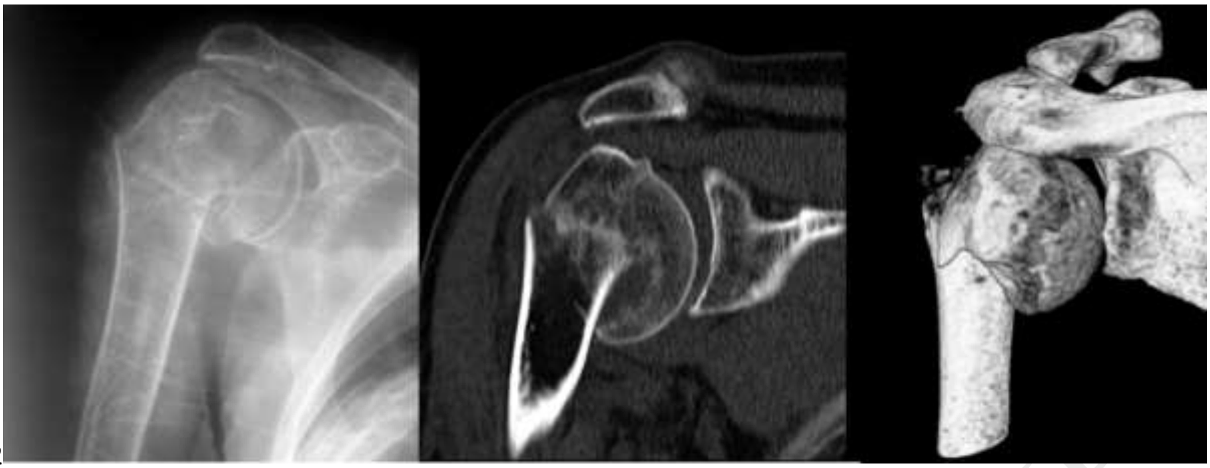
ACCEPTED MANUSCRIPT

Figr-1

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Osteoporotic fractures



Figr-2

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Osteoporotic fractures

Figr-3

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Osteoporotic fractures

Figr-4

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Table 1 Patient demographic characteristics of the osteoporotic and non-osteoporotic groups (Total N = 225).

	Study group (225 pts)	Osteoporotic group (161 pts)	Non-osteoporotic group (64 pts)
Age: mean (range, SD) (yr)	58 (26-95, 32)	69 (49-95, 17)	47 (26-65, 22)
Sex: female (% of the group)	171 (76%)	132 (82%)	39 (63%)
Comorbidities (% of the group)			
-diabetes	30 (13%)	20 (12%)	10 (15%)
-alcohol and nicotine abuse	29 (13%)	19 (12%)	10 (16%)
-previous osteop. diagnosis	19 (8%)	19 (12%)	0 (0%)
Height: mean (range, SD)(cm)	166 (148-192, 39)	165 (148-183,21)	175 (168-192,24)
Weight: mean (range, SD)(kgs)	78 (51-107, 25)	73 (51-101, 22)	81 (64-107, 26)

Table 2 Results of the 7 fracture characteristics in the osteoporotic and non-osteoporotic groups (Total N = 225).

	Study group (225)	Osteoporotic group (163)	Non-osteoporotic group (62)
Codman-Lego			
-type 1	45 (20%)	23 (14%)	22 (35%)
-type 7	110 (49%)	81 (50%)	29 (47%)
-type 12	67 (30%)	58 (36%)	9 (15%)
-head split	3 (1%)	1 (0.5%)	2 (3%)
Length of metaphyseal extension			
<8 mm	149 (66%)	101 (62%)	48 (77%)
>8mm	76 (34%)	62 (38%)	14 (23%)
Integrity of medial hinge			
-yes	117 (52%)	95 (58%)	22 (35%)
-no (disrupted)	108 (48%)	68 (42%)	40 (64%)

ACCEPTED MANUSCRIPT

Osteoporotic fractures			
Metaphyseal comminution			
-yes	97 (43%)	83 (51%)	14 (22%)
-no	128 (57%)	80 (49%)	48 (77%)
Impaction of fragments			
-yes	178 (79%)	153 (93%)	25 (40%)
-no	47 (21%)	10 (6%)	37 (60%)
Comminution of tuberosities			
-yes	80 (35%)	71 (44%)	9 (14%)
-no	145 (64%)	92 (56%)	53 (85%)
Inferior subluxation (> 1 cm)			
-yes	69 (31%)	59 (36%)	10 (16%)
-no	156 (69%)	104 (64%)	52 (84%)

Table 3 Correlations of the 7 radiologic characteristics with osteoporosis in the osteoporotic group.

Codman-Hertel	Osteoporotic group (pvalue)
-type 1	0.56
-type 7	0.29
-type 12	**0.041**
-head split	0.7
Length of metaphyseal extension	
<8 mm	0.33
>8 mm	0.4
Integrity of medial hinge	
-Yes	0.15
-No	0.09
Metaphyseal comminution	
-Yes	**0.001**
-No	0.8
Impaction of fragments	
-Yes	**0.023**
-No	0.27
Comminution of tuberosities	
-Yes	**0.037**
-No	0.5

ACCEPTED MANUSCRIPT

Osteoporotic fractures

Inferior subluxation	
-Yes	**0.029**
-No	0.63

ACCEPTED MANUSCRIPT