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ORIGINAL RESEARCH

Decision-making and treatment results of complex proximal humeral fractures in geriatric patients: retrospective study from a level 1 trauma centre

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Abstract

Proximal humeral fractures are common in elderly, but despite the high incidence, optimal treatment is still discussed and remains a topic of controversy. Nonoperative treatment continuous to be the main modality. However, due to advancements in surgical technology with new techniques and implants, operative treatment could lead to better outcomes and less complications, even in older patients. Decision-making in elderly should incorporate comorbidities, activity level and patient expectations. This study was performed with the intention to find out, if there is a significant difference in treatment strategy and number of operations, in the last five years. Patients older than 65 years with proximal humeral fractures were included. Retrospective analysis of radiographic material and post-injury data was performed, from patients treated in 2015, 2019 and 2020. Last two years were also compared separately to exclude the effect of Coronavirus disease 2019 (COVID-19) pandemic. Epidemiological data assessment, fracture type and treatment strategy were analysed for corresponding years. Statistical analysis was focused on complex three-and four-part fractures. There were no statistically significant differences regarding incidence between the analysed years. Low energy fall was the mechanism of injury in majority of patients. Patients with tuberosity fractures were in average younger than patients in other groups. Although there were more computed tomography (CT) scans done in younger elderly patients, there was no significant difference in number of CTs compared to older patients (year 2015: p = 0.246; year 2019: p = 0.710, year 2020: p = 0.849). The number of operative interventions was the lowest in 2019 (p = 0.498) and the same was for the osteosynthesis using intramedullary nails (p = 0.014). Frequency of reversed shoulder arthroplasty surgeries is increasing, but the difference is not significant (p = 0.390). Both operative and nonoperative treatment result in similar range of motion (ROM) measurements (p = 0.164 for anteflexion. p = 0.163 for abduction), however the groups were not comparable regarding exact fracture types. In the analysed period of 5 years, epidemiology and treatment strategy of proximal humeral fractures did not change. Nonoperative approach remained the main treatment modality. No significant difference was noted in number of interventions or implants used, although there seemed to be an increased trend towards treatment with reverse shoulder arthroplasty (RSA) in complex fractures. A strong correlation was observed between radiographic indications for conservative treatment and actual implementation of it. However, when surgical treatment was indicated using the same radiological criteria, there were more than half of patients, who were not operated on. Radiologic indications are thus not enough for decision-making in treatment of three- and four-part fractures, and patient factors, such as comorbidities and pre-injury activity level, play a major role.

Keywords

Proximal humeral fractures; Elderly; Surgery *vs.* conservative; Intramedullary nailing; Locking plate; Shoulder arthroplasty; COVID-19 pandemic

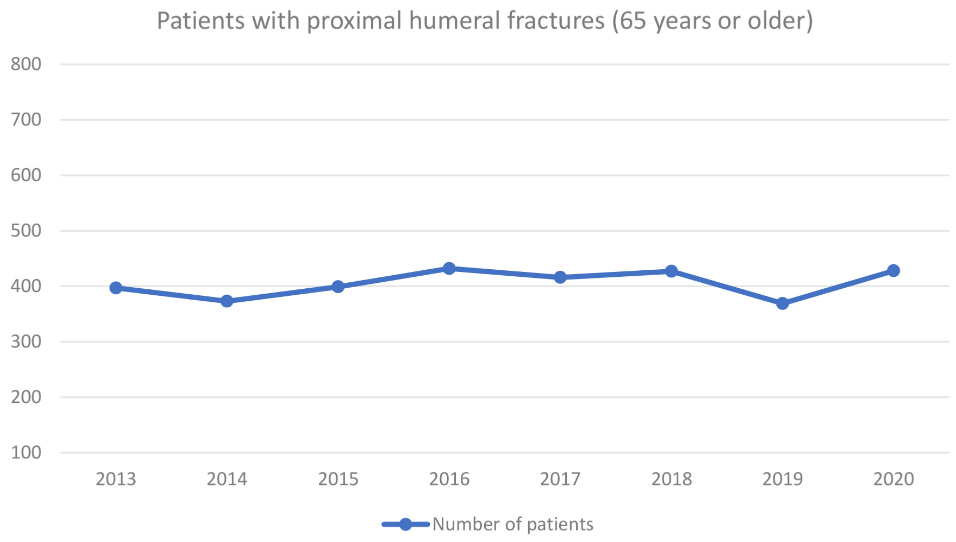

FIGURE 1. Number of elderly patients with diagnosed proximal humeral fractures in the last 7 years.

1. Introduction

Proximal humeral fractures have been described as one of the most common fractures overall (5%) [1, 2] and the third most common fracture in the elderly, after hip and distal radial fractures [3, 4]. Around 85% occur in people older than 50 years of age, and the incidence is the highest in 60–90-year-old patients. Female to male ratio is constant at around 70:30, respectively [2, 5]. Estimated annual rate is of 6 per 10,000 persons in United States and around 700 per year in our central hospital in Slovenia, Ljubljana. Empirically, chronological border is set at 65 years of age. Out of 700 patients, approximately 400 patients on average are over 65 years old (60%). This number has not changed since 2013 (the longest duration of our electronic data collection; Fig. 1). The majority of proximal humeral fractures are sustained during low energy falls in the elderly [6]. Despite its incidence, still no clear guidelines are set regarding optimal treatment. Evidence from randomized controlled trials and systematic reviews is insufficient [7]. Treatment is dependent on patient-specific, fracture specific and surgeon-specific factors [8]. Most fractures can be effectively treated nonoperatively because of the broad cancellous surfaces and rich vascularity, which provide good conditions for healing. Additionally, many fracture patterns result in minimal displacement with adequate bone contact and acceptable alignment, often even with intrinsic fracture stability [9]. Important history elements for decision making include the patient's level of independence, comorbidities, functional demands, and any pre-existing rotator cuff conditions and deficiencies in range of movement. Another important factor to consider is bone density [10, 11]. After introduction of locking plates for osteoporotic fractures in the early 2000s, the rate of operative treatment increased by 25.6% ($p < 0.0001$). This phenomenon was followed by a significant proportional increase in the rate of revision surgeries [12]. Surgical treatment requires an anatomic reduction and stable fixation, which tends to be difficult, especially in osteoporotic bone [13]. RSA incidence is thus increasing in the elderly, in contrast to hemiarthroplasty (HA) and osteosynthesis (OS) [14].

The objective of our study was three-fold. First, to identify a difference in treatment strategy for displaced three- and four-part humeral fractures in the last five years, if such difference should exist; for example, if RSA is implemented more often for complex fractures now, than in previous years (as literature would suggest). Second, to compare functional results between conservative and surgically treated patients in complicated proximal humeral fractures. And third, to see how big of an impact do x-ray indications for surgery have on actual treatment decision.

2. Materials and Methods

A retrospective search for data on proximal humeral fractures was done in August of 2021, in University Medical Centre of Ljubljana. We included patients, who presented in our Emergency department and were diagnosed with a proximal humerus fracture. The intention was to look for differences in treatment of complex 3- and 4-part fractures in the last five years. Since the year 2020 was deemed as a "COVID year", we decided to determine, if treatment of these fractures was altered due to COVID-19 pandemic. In Slovenia, this pandemic and problems related to it, began enlarging after March of 2020. If differences between 2020 and 2019 would not be significant, then we could continue with comparing the five-year period between 2015 and 2020 in choices for types of treatment and successive outcomes.

2.1 Patient selection

Patients with shoulder injuries included in the study were primarily assessed in Emergency department of University Medical Centre (UMC) Ljubljana. They were clinically examined regarding shoulder injury, with description of neurovascular status, distal to the injury, and possible additional injuries. Two standard radiographs were taken, one in coronal plane (an antero-posterior (AP) view—with the central ray tangential to the glenoid surface) and one in scapular plane (an Y view—with the central ray perpendicular to the glenoid). A CT scan

TABLE 1. ICD-10 proximal humeral fractures classification.

S42.20	unclassified proximal humeral fractures
S42.21	humeral head fractures
S42.22	surgical neck fractures
S42.23	anatomical neck fractures
S42.24	greater tuberosity fractures
S42.29	other and multiple parts

of the injured shoulder was done at the discretion of the treating physician, to further characterize the fracture in detail and to determine articular involvement.

A standardised coding system was employed—ICD-10 (International Classifications of Diseases). Diagnoses, with a range from S42.20 to S42.29 (proximal humeral fractures), were considered (Table 1).

Inclusion criteria were patients 65 years of age or older, with diagnosed proximal humerus fracture in the Emergency department.

Exclusion criteria were patients with associated ipsilateral upper limb fractures (that would in any way interfere with rehabilitation protocol), open injuries, deformity from previous injuries, severe arthrosis, primary tumour or metastatic fractures, or those with associated vascular injuries. We also didn't include patients, where we couldn't confirm a fracture on radiographs.

We documented all of patients' data in in years 2019 and 2020, with a portion of data missing in 2015. In all the data, patient information was concealed prior to statistical analysis, and files with patient identification characteristics were discarded.

Data describing comorbidities, pre-injury level of activity, level of independence, occupation and functional demands was only available for a small group of patients and has not been incorporated in our study for analysis. We therefore assumed, that any deviation from x-ray indications for surgical treatment would be based with consideration of these knowingly important factors.

Active movement measurements in anteflexion and abduction were considered for functional analysis at the last follow-up visit. We considered only patients, who had at least 3 months (90 days) of follow-up period. This period has been determined only for functional outcomes and not for complications assessment.

Complications were described and noted at the last follow-up visit. They however could not be properly analysed, since the last two years were just recent and not enough time has passed to assess late complications. A discrepancy could thus occur between years. Complications were divided into seven categories: excessive varus angulation (empirically set border of more than 30° from physiological varus of 135°), intraarticular screw perforation, nonunion, avascular osteonecrosis, tuberosity avulsion and/or resorption, infections and other. Complications were assessed based on the last x-ray image available.

Three doctors, trained in a shoulder-specific trauma unit, have gathered the data and interpreted radiographs taken at the time of injury and at follow-up visits. The final evaluation was done on 347 patients with 3- and 4-part fractures.

2.2 Fracture classification

Muscles with tendons, inserted in proximal humeral bone and shaft, produce reliable deforming forces on bone fragments. Muscles that produce these forces include pectoralis major, deltoid, and rotator cuff muscles—this causes distinctive fracture patterns. For practical purposes, we divided groups as follows: one-part fractures are described as an abruption or avulsion fractures of the greater or lesser humeral tuberosity. Two-part fractures are fractures through surgical or anatomical humeral neck. Three- and four-part fractures are classified accordingly with addition of fracture parts. Neer's original classification was thus modified, since Neer described one-part fracture as a nondisplaced fracture in any area of the proximal humerus [14]. We also modified Neer's original displacement criteria for fracture classification, which are more than 1 cm of separation between fragments and more than 45° of rotation in a bone segment. Instead, parts were counted as separate, if fracture line was seen on x-ray radiographs or on CT scans. Head split fractures and glenohumeral fracture-dislocations were mentioned separately. Modification of Neer's criteria created three groups: nondisplaced, satisfactory (within Neer's criteria) and displaced (outside Neer's criteria; Fig. 2). If a fracture pattern was evaluated as displaced, radiographic indication for surgical treatment was set, not considering age or other patient characteristics. We wanted to see if clinical indications for surgery, as they were realised, did in fact reflect radiographic indications.

2.3 Treatment methods

Nonoperative treatment was the mainstay for most patients. Most common surgical treatment was anatomical reduction and fixation, either with locking plate or intramedullary nail. Reduction of the fracture with intramedullary nail was usually done indirectly in a closed manner, with nail insertion through a minimally invasive approach. In 3- and 4-part fractures, anatomic reduction of tuberosities still required a classic open approach. In some fractures, where reduction was not possible due to fracture pattern or poor bone stock, patients were treated with arthroplasty. Indications for arthroplasty are further revised in discussion, but for the majority of elderly patient, treatment of choice is now a reversed shoulder arthroplasty (RSA).

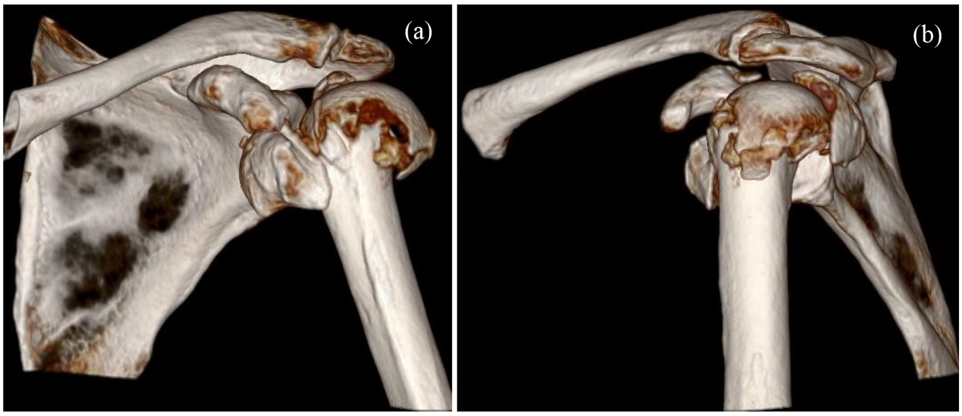

FIGURE 2. 3D CT scan of a displaced 4-part valgus proximal humerus fracture. (a)—coronar view of left shoulder, (b)—sagittal view of left shoulder (same patient as in Fig. 3, right picture, reversed shoulder arthroplasty (RSA)—refer to Fig. 3).

2.3.1 Surgical technique

Implants were inserted through two standard surgical approaches: deltopectoral and anterolateral (trans-deltoid) approach.

Deltopectoral approach: Patient is positioned in a beach chair position. A vertical skin incision is made just above the coracoid process and extended distally at the medial border of deltoid muscle. Dissection of fatty tissue is made to muscle fascia, overlying deltoid and pectoralis major muscles. An interval is identified, and a careful dissection starts between the two muscle bellies. Cephalic vein, which runs in this interval, is a useful landmark. Careful dissection medial to cephalic vein is done, until the under surface of the groove exposes the clavipectoral fascia. Fascia is then incised along the lateral border of the conjoined tendon (m. coracobrachialis and m. biceps brachii, caput brevis). Underneath is a subdeltoid bursa, which must be removed in order to expose the tendons of the rotator cuff and fracture fragments.

Anterolateral approach: Patient is positioned in a beach chair position. A vertically orientated skin incision is made, starting at the anterior lateral border of the acromion and distally in the line of humeral shaft. The skin incision should not extend distally for more than 5 cm, to protect the axillary nerve. Superficial dissection is made by undermining the subcutaneous tissue and sharp dissection in the upper part of deltoid raphe between the clavicular and acromial part of the muscle, with blunt dissection in the lower part (to avoid damaging the axillary nerve). Subdeltoid bursa is excited as much as possible, so the fracture lines are clearly visible, as well as insertions of rotator cuff muscles. Axillary nerve is identified approximal 5–7 cm from the edge of the lateral border of acromion distally and must be always protected.

Deltopectoral approach is rarely used in our practice. We use it mainly for implantation of a standard shoulder prosthesis (due to indications such as massive rotator cuff tears or avascular necrosis of the humeral head). We also use deltopectoral approach, when most of the problem we need to address is in the anterior part of the shoulder (*e.g.*, lesser tuberosity avulsion, subscapularis tendon rupture, anterior fracture-dislocation of proximal humerus).

Anterolateral approach is our "working horse" approach. It is utilised in osteosynthesis with locking plate or intramedullary nail, and for hemi- or total reverse fracture arthroplasty. This approach gives a better exposure to the posterior part of the proximal humerus, as well as to the glenoid surface.

2.3.2 Implants

Utilised implants in our medical centre for proximal humeral fractures were:

Anchor sutures: Super Revo® suture anchor 5.0 mm, Con-Med corp. (Utica, NY, USA) (Fig. 11).

Locking plate: Philos® plate, DePuy Synthes (Massachusetts, CA, USA) (Fig. 11).

Intramedullary nail: Targon PH®, B. Braun (Melsungen, Germany) (Fig. 3).

Hemiarthroplasty: Aequalis® FX Shoulder system, Tornier Inc. (Bloomington, MN, USA) (Fig. 3).

Reversed fracture endoprosthesis: Aequalis® Reversed FX Shoulder prosthesis, Tornier Inc., (Bloomington, MN, USA) (Fig. 3).

Reversed standard endoprosthesis: Aequalis® Reversed II Shoulder System, Tornier Inc. (Bloomington, MN, USA) and Aequalis® Ascend Flex Convertible Shoulder system, Tornier Inc. (Bloomington, MN, USA).

2.4 Rehabilitation protocol

Postoperatively patients were placed in a shoulder brace and immediately began with elbow exercises. Passive physiotherapy regimen was initiated on the second day after surgery, without stressing the bony fixation or the soft tissue repair. The course of physiotherapy was based on the injury pattern, fixation strength, bone quality, and patient compliance. If fixation construct was at risk, a more cautious protocol was employed, with a period of shoulder rest for a couple of weeks, with only elbow movements and pendulum exercises. All initial orders and instructions for progression of physiotherapy were given by the treating surgeon in charge. Even in conservatively treated patients with stable fracture patterns, passive range of motion exercises began as soon as pain subsided, which was

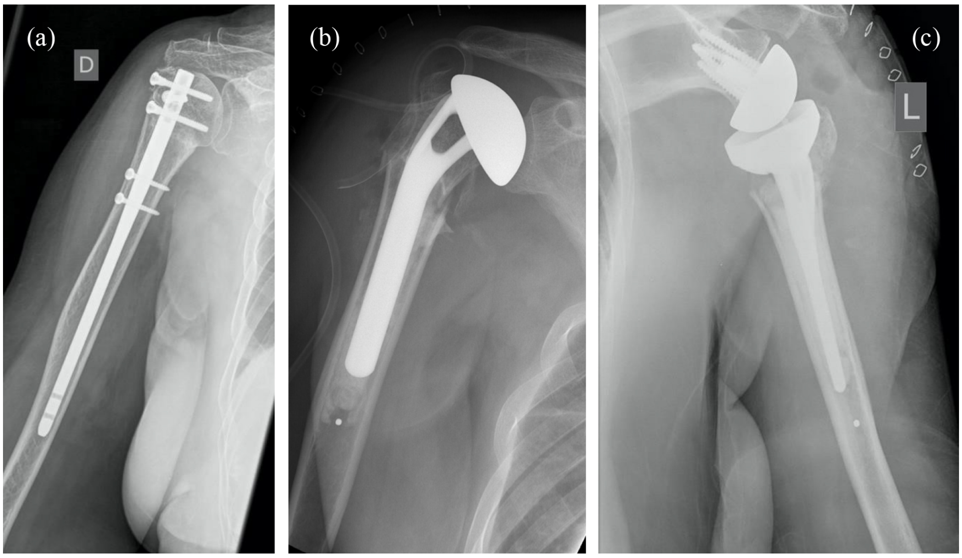

FIGURE 3. Types of surgical intervention. (a)—intramedullary nail fixation, (b)—partial fracture endoprosthesis, (c)—reversed shoulder endoprosthesis. Fixation of a 3-part fracture with intramedullary nail (left), implantation of partial endoprosthesis (PEP) after a 4-part fracture (middle), RSA after a 4-part fracture (right).

usually at around two weeks postoperatively. Quick mobilisation of joints after surgery and in conservative treatment is the mainstay method of physiotherapy at our clinic, intended to avoid late complications such as stiffness and poor mobility.

2.5 Follow-up

Patients had variable control intervals, but visits were frequent in the beginning and are planned according to the patients' needs regarding their physical and health status, fracture type and mode of treatment. The control intervals are then progressively longer towards the end of treatment. Radiographs would then be taken at every follow-up visit and very rarely would be discarded due to good clinical state and absence of symptoms. First check-up was usually done after a couple of weeks, when an AP (anteroposterior) and an Y (lateral) radiograph where taken and final treatment strategy would at this point be decided by a traumatologist. In rare cases, when a displacement, malunion or an improper healing would occur, another treatment strategy would be decided. In late complications, treatment might shift from conservative to surgical even after a year of follow-up or more (*e.g.*, avascular necrosis, nonunion, malunion). We don't have a standardised forms available for patients in control clinic, so active mobility described by treating surgeon, is our main form of following progression of rehabilitation and functional outcome. Active mobility is described in degrees of movement in four directions: anteflexion (forward elevation), abduction (outward elevation in scapular plane), external rotation (90° of elbow flexion with arm at the side of the chest) and internal elevation (arm behind body, described in vertebrae level by reaching the highest point with hand). The final estimation would be determined by functional, or for older patients pain-free status, at the last follow-up visit.

2.6 Primary goals

Our primary intended goals were:

Were there fewer operations done due to measures for constraining the viral spread in COVID-19 pandemic?

Is our treatment of 3- and 4-part proximal humeral fractures now similar to that in 2015 (number of operations and choice of surgical implants)?

Was active movement in abduction and anteflexion significantly different in surgical *vs.* conservative groups in 3- and 4-part fractures after at least 3-month follow-up period.

Was there a significant difference between radiographic indications for surgery and the type of treatment that was in the end employed?

2.7 Statistical analysis

Data was collected and processed in Excel, Microsoft 365, version 16.53 (Microsoft corporation, Redmond, WA, USA). Analysis was done with statistical software R 4.0.3. (R Foundation for Statistical Computing, Vienna, Austria) [15]. Additional packaged used were readxl (R Studio, Boston, MA, USA) [16] and ggplot2 (R Studio, Boston, MA, USA) [17].

Test utilized were Generalized linear model (GLM) with Gaussian distribution of errors and an identity link function, and Pearson's Chi-squared test for count data. The level of significance was defined to be $p < 0.05$.

3. Results

3.1 Descriptive statistics

The number of patients included in the full analysis is 197 out of 399 for the year 2015, 238 out of 269 for the year 2019 and 325 out of 428 for the year 2020.

Patients, that were missing in the year 2015, were searched for manually with intention of comparing number of surgeries and implants used in 3- and 4-part fractures. Additional 13 patients were found and analysed only in section 3.5.

The main reasons for exclusion were diaphyseal humeral fractures, previous deformities of the glenohumeral joint, se-

TABLE 2. Number of patients by separation into part-groups in each year (for classification see subsection 2.2—Fracture classification).

number of parts/year	2015	2019	2020
1-part	49 (49%)	18 (18%)	33 (33%)
2-part	58 (18%)	117 (37%)	140 (44%)
3-part	61 (23%)	78 (30%)	123 (47%)
4-part	29 (35%)	26 (31%)	29 (35%)

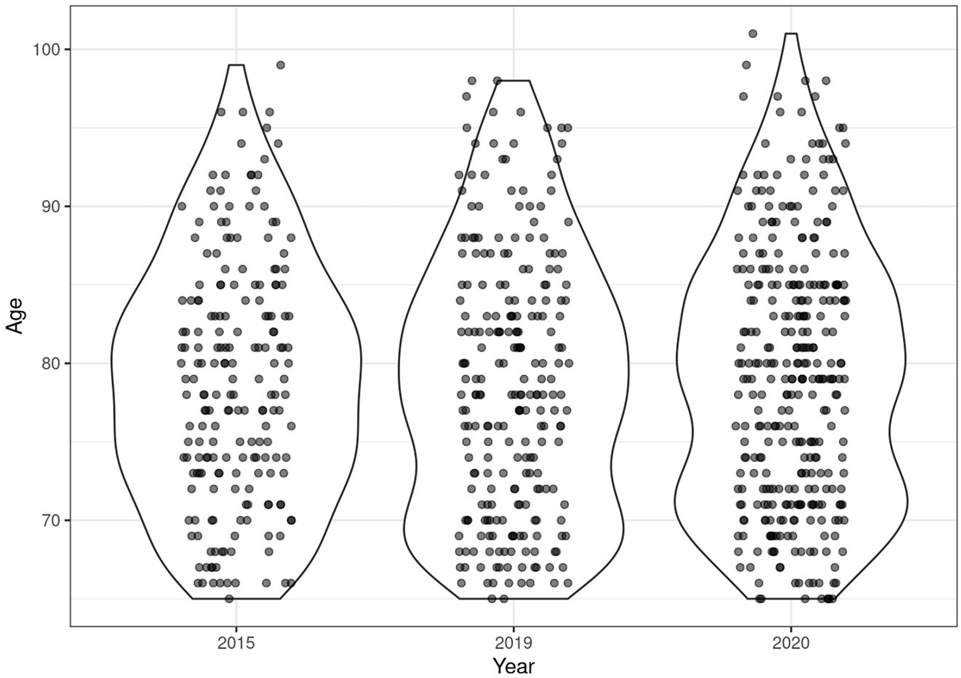

FIGURE 4. Age distribution in each year.

vere arthrosis, metastatic or primary tumour fractures and any fractures in ipsilateral upper limb, that would interfere with rehabilitation protocol and functional outcomes. There were also quite a few administrative errors, such as wrong classification codes (*e.g.*, elbow fracture instead of proximal humerus) and double or even triple administrative entry of the same patient. Some patients had fracture diagnosed, when in fact there was no skeletal injury seen upon revision of radiographs, or there were signs of older, healed fracture. There was approximately 20% of patients treated surgically and around 80% of patients treated conservatively in each year (38 patients (19%) in 2015, 38 (16%) in 2019 and 68 (21%) in 2020).

3.2 Age distribution and fracture types

As aforementioned in methods section, patients were divided in groups by fracture types. Table 2 shows the distribution of patients by fracture-parts in each year. Age distribution is displayed in Fig. 4. To assess difference in age means between groups, we utilized Generalized linear model (GLM) with Gaussian distribution of errors and an identity link function. $p = 0.5$. Average in age was 78.9 years in 2015, in 2019 78.7 years and in 2020 79.1 years. No significant differences were found. Results: standard error (SE) = 0.57 for 2015, $p = 0.828$ with SE = 0.79 for 2019, and $p = 0.743$ with SE 0.74 for 2020. Groups are comparable in aspect of age.

There was however an uneven distribution according to part-numbers. Patients with one-part fractures (fracture/avulsion of the greater or minor tuberosity) were in average statistically significantly younger than patients in other groups. GLM test with Gaussian distribution of errors and an identity link function, $p = 0.5$. Results: 2-part: $p < 0.001$, SE = 0.93; 3-part: $p = 0.009$, SE = 0.95); 4-part: $p = 0.032$, SE = 1.20). Displayed in Fig. 5.

3.3 Mechanism of injury

Mechanism of injury was divided into low and high-energy injuries. Low energy injuries were falls from standing height, falls from chair or bed, injury by pulling on the arm or injuries while transferring the patient, and others. High energy injuries were falls down the stairs, falls while skiing, injuries in car accidents, falls down a hill, falls while riding a bike, and others. In 3- and 4-part fractures, 274 (86%) patients sustained proximal humerus fractures by low-energy falls, while 45 (14%) patients had high-energy mechanisms of injury. 33 patients had no available data about the mechanism of injury. Average age was 79 years in low energy falls and 75 years in high-energy falls.

For detailed analysis we further focused only on complex 3- and 4-part fractures.

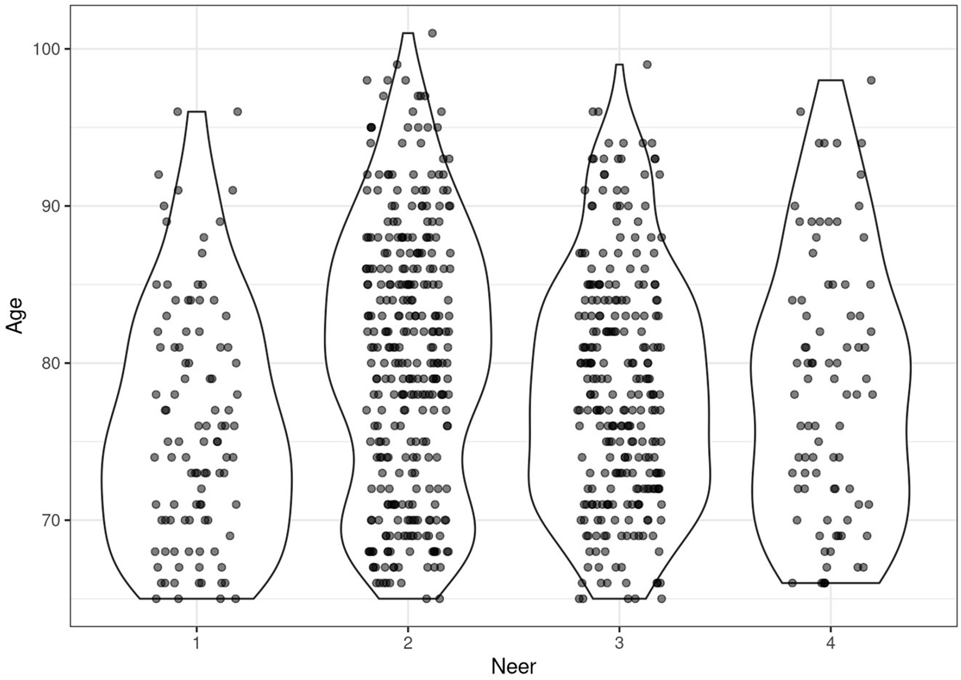

FIGURE 5. Distribution of patients in age, separated in four groups (1-, 2-, 3- and 4-part fractures).

3.4 CT diagnostics

CT scans are used to better understand fracture patterns and to help with the decision making in treatment of these fractures. We wanted to know if age was a factor when deciding for a CT scan. Using GLM test with Gaussian distribution of errors and an identity link function, no statistically significant differences were noted in each year; $p = 0.5$. Results: year 2015: SE = 1.74, $p = 0.246$; year 2019: SE = 1.77, $p = 0.710$, year 2020: SE = 1.67, $p = 0.849$. Although CT scans were less frequently done as age progressed, this difference was not big enough to be statistically important.

3.5 How did treatment strategy differ between years

We chose two recent years (2019 and 2020), to avoid a possible influence of COVID-19 pandemic on interpretation of our results.

What interested us was, if we operated less in the recent two years than in the year 2015, and if there were different surgical methods utilised (implants used). Surgically treated patients, that were missing in year 2015 due to data loss, were manually retrieved for purpose of analysis in this sub-section. There were 13 additional patients added to the year 2015. Absolute number of operations was 42 in 2015, 24 in 2019 and 42 in 2020.

Chi-square test was used for statistical analysis; a moderate statistically significant difference was found between number of surgical procedures in compared years; $p = 0.4979$ ($p = 0.05$). Year 2019 had a lower influx of patients with proximal humeral fractures (section 1, Fig. 1) and fewer surgical procedures on these patients. We cannot conclude a relevant pragmatic biological difference, based on this analysis.

Next question was, how did surgical strategy differ between years. In other words, do we use different implants now than we did five years ago. Fig. 6 represents percentage of implants used in each year. We focused on commonly used implants for 3- and 4-part fractures, which are locking plate, intramedullary nail, and reverse shoulder fracture prosthesis (including a small number of standard reverse prosthesis). For implant details refer to sub-section 2.3.2. We should stress, that we did not consider hemiarthroplasty (HA), which was done in two patients in 2015, and an osteosynthesis with suture anchors, which was done in one patient in 2015. There was not enough of these cases to consider them for analysis or further interpretation.

Using Chi-squared test with $p = 0.5$ we found a statistically significant difference between number of surgically treated patients with intramedullary nails in the year 2019. Results: chi squared = 8.5806, degree of freedom (DF) = 2, $p = 0.0137$. Results in plate and RSA groups were chi-squared = 0.63636, DF = 2, $p = 0.7275$, and chi-squared = 1.8846, DF = 2, $p = 0.3897$, respectively There were statistically significant less intramedullary nails used in year 2019, than in 2015 and 2020.

3.6 Functional results

Based on available data, we decided to constrain functional outcomes on two numeric measurements: anteflexion (front elevation of arm in sagittal plane), and abduction (side elevation of arm in coronal plane); both measured in degrees of movement. We only considered patients, that had at least 90 days of follow-up. Results are displayed in Fig. 7 and Fig. 8.

There is better active movement after nonoperative treatment in younger elderly than in surgically treated patients but gets progressively worse with age. Operative treatment has a steady minimal decline in active movement, considering patient age. Although decline is more evident in conservatively treated patients, there is no statistically significant difference between operative and nonoperative treatment. We used GLM

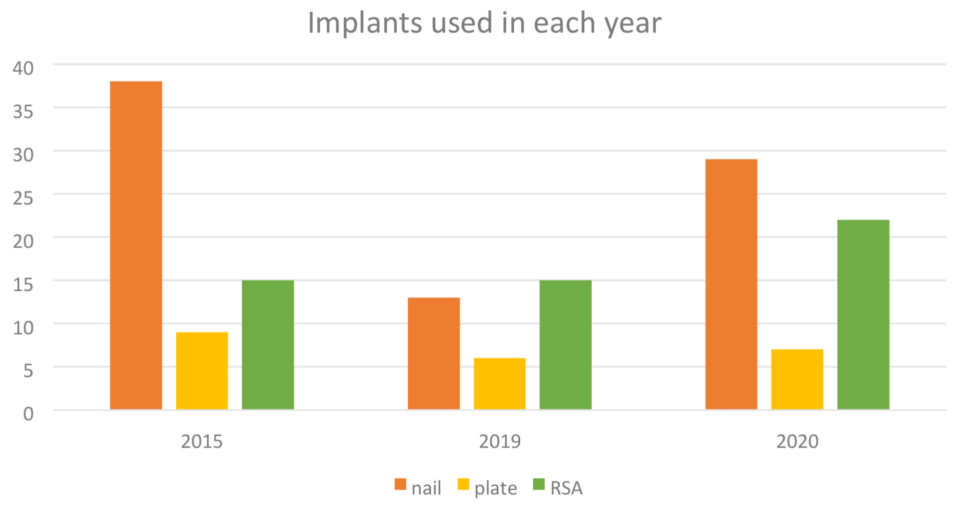

FIGURE 6. Implants used in each year—presented in percentage of surgical procedures combined.

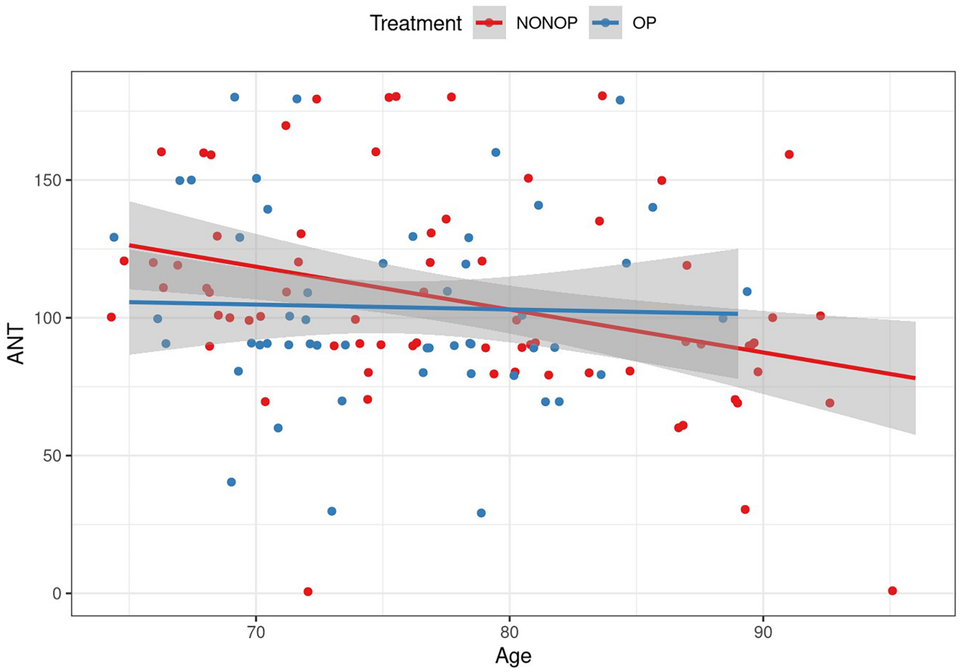

FIGURE 7. Display of final active movement in anteflexion, comparing operative and nonoperative treatment. Y-axis: anteflexion movement, measured in degrees; x-axis: age, measured in years. AND—anteflexion, OP—operated patients, NONOP—non-operated patients.

test with Gaussian distribution of errors and an identity link function; p = 0.5. Results for anteflexion: SE = 0.9845, p = 0.164. Results for ABD: SE = 0.9157, p = 0.163.

3.7 Correlation between radiographic indications for surgery and implementation of surgical treatment

We considered Neer displacement criteria (more than 1 cm of fracture separation and more than 45° of rotation), as grounds for surgical indication. We only looked at radiographic material and did not consider factors such as age, comorbidities, bone density, functional requirements, or any other patient-related aspect. We agreed almost entirely, when nonoperative treatment was indicated. But when surgical treatment was radiographically indicated, we still had not decided for surgery in more than half of cases (Fig. 9). 69 patients (out of 131 in nonoperative group) were treated conservatively, although x-ray criteria were met, while only 3 patients (out of 124) were treated surgically, without x-ray indications. This indicates that patient factors play an important role in decision making.

There seems to be an agreement in indications for conservative treatment, but not for operative treatment. Different colours of dots represent each year. The left shape of OP column demonstrates that we tend to operate more on chronologically younger individuals.

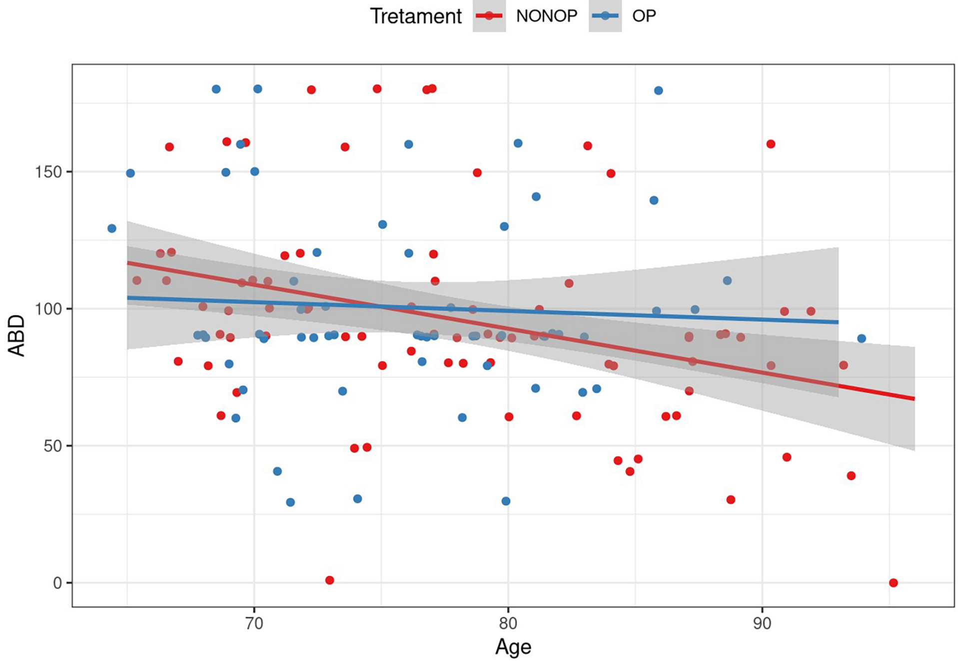

FIGURE 8. Display of final recorded active movement in anteflexion, comparing operative and nonoperative (NONOP) treatment. Y-axis: anteflexion movement, measured in degrees; x-axis: patients' age, measured in years. ABD—abduction, OP—operated patients, NONOP—non-operated patients.

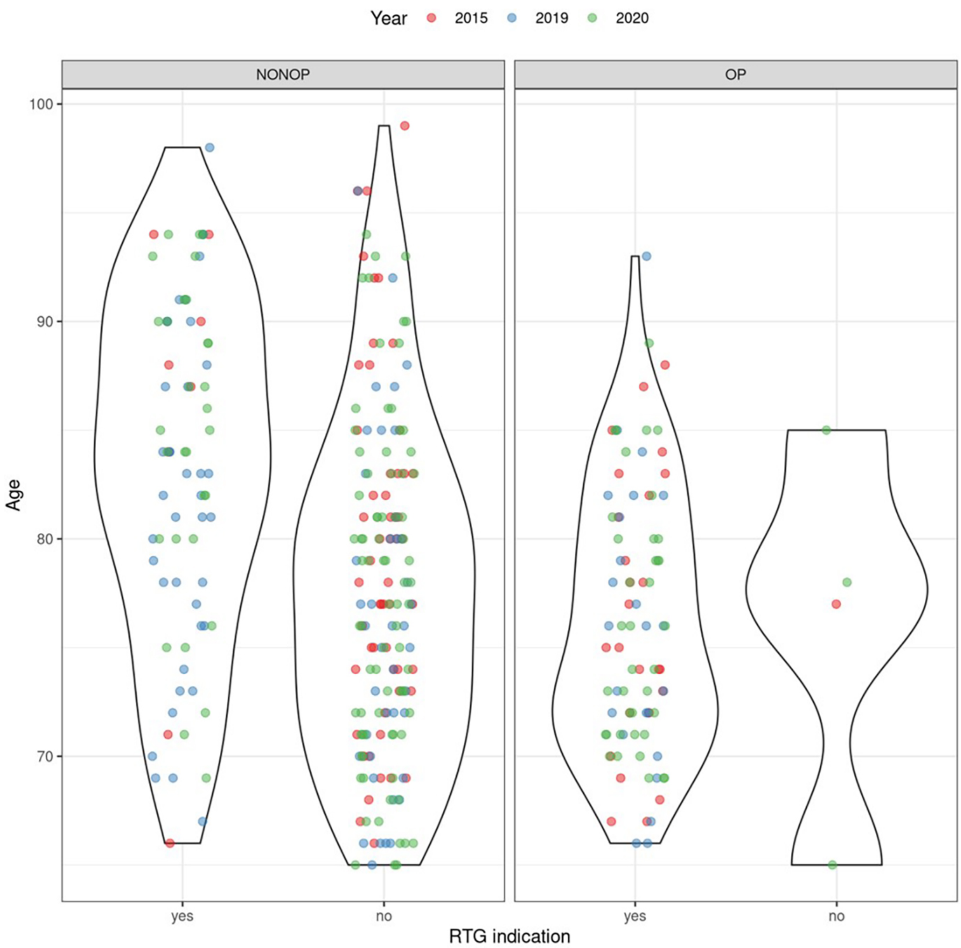

FIGURE 9. A display of radiographic indications for surgery (lower x-axis), with type of treatment that was employed (top bar, NONOP *vs.* OP) in three- and four-part proximal humeral fractures.

TABLE 3. Number of patients and complications in 3- and 4-part fractures for each year.

	2015	2019	2020	together
number of patients	92	104	152	347
varus displacement	9 (9.8%)	12 (11.5%)	2 (1.3%)	23 (6.6%)
screw penetration	2 (2.2%)	0 (0 %)	2 (1.3%)	4 (1.2%)
AVN	3 (3.3%)	3 (2.9%)	3 (2%)	9 (2.6%)
greater tubercle resorption/migration	0	8 (7.7%)	6 (4%)	14 (4%)
nonunion	2 (2.2%)	1 (1%)	2 (1.3%)	5 (1.4%)
infection	0	0	0	0
others (dislocation, ossification, scapular notch.)	3 (3.3%)	4 (3.9%)	2 (1.3%)	9 (2.6%)
in sum	18 (19.6%)	28 (26.9%)	17 (11.2%)	62 (17.9%)

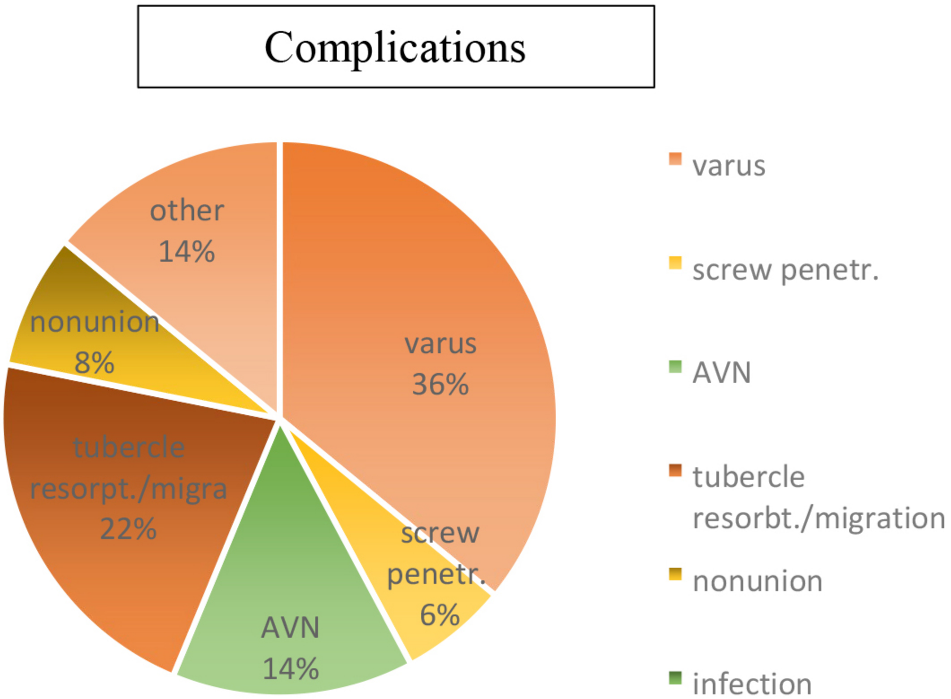

FIGURE 10. Display of most common complications after treatment (in percentages).

3.8 Complications and revision rates

Greater tubercle resorption and/or migration was seen in 7 patients with RSA fx, 5 in conservative treatment, in 1 patient with intramedullary nail and in 1 patient with locking plate (example shown in Fig. 11). Avascular necrosis (AVN) was seen in 3 patients with fracture through anatomical neck and 3 patients in fracture through surgical neck; 3 patients who were treated nonoperatively also had AVN. Screw penetration in all 4 cases was seen because of bone collapse due to AVN. Varus angulation, malunion and nonunion was only seen in conservatively treated patients. Absolute numbers with percentages of complications are shown in Table 3, and proportions of complications are displayed in Fig. 10.

Reason for revision surgeries and interventions (Table 4):

Year 2015: AVN of humeral head—RSA standard, marked dislocation—Targon PH, varus angulation—Philos, nonunion—Targon PH. Year 2019: avulsion of the greater tubercle—refixation with suture anchors, AVN of the humeral head—RSA (intended). Year 2020: nonunion—not operated (patient's decision), locking screw perforation—osteosynthetic material removal, massive rotator cuff tear—RSA (intended), AVN of humeral head—RSA (intended).

4. Discussion

4.1 Introduction

Three and four-part fractures occur more often in elderly with poor bone structure and have been analysed separately from other types of proximal humeral fractures in several published studies. Management of these fractures spans from conservative treatment to fixation with locking plates and intramedullary nails, and more recently, treatment with shoulder

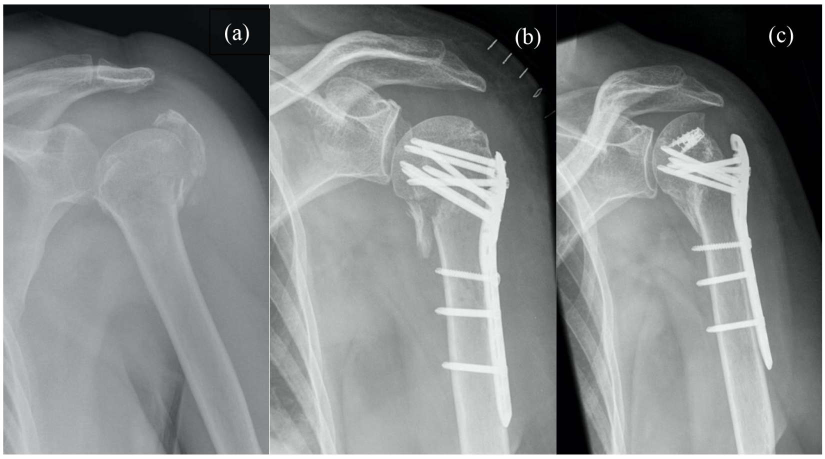

FIGURE 11. Proximal humerus surgical neck valgus fracture and a greater tuberosity fracture (3-part fracture). (a)—fracture x-ray on the day of the injury, (b)—open reduction and fixation with locking plate, (c)—revision surgery—removal of proximal locking screws and fixation of rotator cuff tendons with suture anchors, after a complete resorption of the greater tuberosity (right).

TABLE 4. Revision rates for each year (in brackets).

	2015	2019	2020
revisions suggested	4 (9.5%)	2 (8.3%)	4 (9.5%)
revisions done	4	1	1

arthroplasty. Because of various patterns of fractures and different dislocation configuration between parts, uniform decision making is even more difficult than in one- and two-part fractures. This gives a more disperse freedom of choice for the treating surgeon. The main question in our study is, did we make the right decisions, or in other terms, when is surgical treatment better than conservative? As with all advancements in surgery, new techniques and new implants tend to make decisions for treatment strategy even more inclined towards surgery. Advancements in fracture fixation technology have led to development of fixed angle locking plates, that maintain angular stability under load, have a wide spread of locking screws and two calcar screws, that support medial column [18, 19]. Correct placement of calcar screws can decrease rates of reduction loss and hardware penetration [20]. Arthroplasty also brings new solutions with different material choices, implant positioning and modality options.

4.2 Epidemiology

Although population is ageing faster, and a percentage of people older than 65 years of age is getting larger [21], proximal humeral fractures seem to be occurring at a steady number in recent years at our clinic (Fig. 1). Increase in number of operations, that would reflect overall ageing of population, is not evident from our data. Reasons for that might be several; a short time period (data only from 2013), simultaneous improvement in fall-prophylactic behaviour, more frequently prescribed anti-osteoporotic medication and socially encouraged fall-prophylactic propaganda. Proximal humeral fractures occur in a vast majority of patients by a mechanism of a simple fall, as was also the case in our data review. 86% sustained fractures by low energy injuries and were in average four years older, than patients with high energy injuries. Such reports have been published by Clement *et al.* [22] in their study of proximal humeral fractures epidemiology and outcome-predictable factors, in 2014. The most common mode of injury was a simple fall from a standing height (n = 604, 94.8%), with the remainder being due to a fall from a height (n = 15, 2.4%), road traffic accident (n = 10, 1.6%), direct blow or assault (n = 6, 0.9%) and sport (n = 2, 0.3%). There was no significant difference in the mechanism of injury according to age group ($p = 0.11$, chi squared).

4.3 Operative and nonoperative treatment

Conservative treatment remains the most common modality employed for proximal humeral fractures to date (67 to 86%) [5, 23, 24]. We know now, from reports of previous and most recent studies, that minimally displaced or displaced valgus impacted fractures (even complex 3- and 4-part fractures), do well with conservative treatment [25–27]. This is continuously confirmed throughout our practice. We also know that excessive varus deformity, tuberosity avulsion and articular fragment displacement, may often lead to poor functional results [28, 29] and we should therefore be more inclined towards surgical treatment. Voigt *et al.* [28] studied the impact of varus deformity on supraspinatus and deltoid forces. Regardless of the fracture type, the initial varus deformity was the preoperative variable, that had the greatest influence on outcome. Patients with a valgus impacted fracture had better final outcomes (a mean Constant-Murley score of 75 points), whereas those with varus type fracture had a mean Constant-Murley score (64 points) that was comparable with HA patients [28]. Due to their findings, varus deformities of more than 20° should not be accepted intraoperatively.

They discuss further that difference may be due to the way plate functions in each group. In valgus, the plate acts as a mechanical strut under compressive forces, while in a varus-type fracture pattern, the plate functions as a tension band by pulling the humeral head out of varus. Therefore, with poor bone quality, varus-type fractures place the implant at a mechanical disadvantage and failure is determined by the pull-out resistance of the screws rather than by the compressive strength of the bone [28]. A retrospective analysis of displaced proximal humeral fractures treatment, classified by Orthopaedic Trauma Association (OTA) 11 A–C, was made by Goch *et al*. [30]. Open reduction and internal fixation with a locking plate was made in all cases. Comparison between younger (aged 55–69 years) and elderly patients (above 70 years of age) showed no significant differences in respect to active range of motion (forward elevation, $p = 0.481$; external rotation, $p = 0.423$; internal rotation, $p = 0.091$), Disabilities of Arm, Shoulder, and Hand (DASH) scores ($p = 0.262$), complication rates ($p = 0.644$), and revision rates ($p = 0.524$). Authors notably stress, that the results of their study indicate older patients can be surgically treated with good results, but with nonoperative treatment still as first choice due to the nature of fracture or their overall state of health. Many factors must be considered in the decision-making process, with patient independence and activity level crucial for final outcomes [9]. They conclude, that despite complex fracture patterns and poor bone quality, surgical fracture fixation can provide reliably good results in the hands of a skilled surgeon, with low complication rates, even in elderly patients [30]. Of course, patients retrospectively screened for this study, had indications for open reduction with internal fixation (ORIF) with a locking plate set by the treating surgeon, and were not randomised to different treatment modalities. Hence, we could interpret their results as a safe and successful method for carefully selected elderly patients with displaced proximal humeral fractures.

A study, which has shaken the world of modern shoulder trauma surgery, is the ProFHER PROximal Fracture of the Humerus: Evaluation by Randomisation (ProFHER) trial. Published in JAMA in 2015 by Rangan *et al*. [31], their main finding was that there was no significant difference between surgical treatment compared with nonsurgical treatment. Patients enrolled had displaced proximal humeral fractures involving surgical neck. Despite the impact of this study with clear and robust conclusions drawn, its limitations are numerous. One such limitation, which is the reason why we only mention this study, and do not discuss it further, is the wide population sample spectrum, which rangers from 16 years and above. This is, in our opinion, not comparable with population sample in our study.

4.4 Classification and decision-making

Decision making sole by evaluation of radiographs, is of limited value, and should not play a role as an only indicator for treatment. Still, no agreement exists, as to what should be the defined limits of fracture displacement, amenable for surgery. In general, surgical treatment should be considered in head-to-shaft displacement of >50% of the diaphyseal diameter and varus or valgus angulation (nonimpacted) of more than 20° from the physiological 135° head-to-shaft inclination [25]. By Codman's and Neer's definition, a fragment is considered displaced if it is separated more than 1 cm or angulated more than 45°; however, there is no evidence-based indication for this definition of displacement [27]. We decided to take Neer's displacement limits as our radiographic indicative measurements for surgical treatment, because these are also radiological limits that guide our decision in practice in our facility. Measurements were taken on x-ray radiographs, and if possible, on CT scans. Decisions for classifying a fracture into part-groups were subjective to each surgeon's interpretation. Each surgeon was appointed one year in question for collection of data and radiographic interpretation. That is why there might be a discrepancy in number of patients in part-groups. We also suspect that a low number of intramedullary nail fixations in year 2019 might have come from a missing proportion of three- and four-part fractures, that were placed into two-part group and were hence not incorporated for further analysis. This low number of fixations cannot be generalized into broader population other than for treated patients in our own institution.

Although we did not have the appropriate information available for analysis of factors that knowingly influence decision-making process, the deviation from x-ray indications for surgery are assumingly because of combination of these factors. Whether the leading cause for conservative treatment, in an otherwise surgery-amenable fracture, is age, comorbidities, pre-injury activity level or something else, needs to be further investigated.

4.5 Bone density

Bone density is a factor we should consider when we are leaning towards surgical intervention. If bone density is appraised as too low, it is reasonable to consider implantation of shoulder prosthesis. Bone density is a predictor of surgical reduction quality and screw cut-out [10, 11]. Reduction loss can be as high as 23% at 3-month follow-up evaluation [32]. Jung et al reported, that 7% of patients after ORIF with locking plates had undergone revision surgeries [11], with low bone density being the most significant risk factor for failure. Loss of bone can be improved by augmenting fracture fixation construct with cortical allograft. Most common allograft is fibula strut allograft (FSA), which can be placed intramedullary on medial cortex (varus type fracture, loss of medial support), or extramedullary on lateral side (valgus type bone loss) [33]. Several studies have compared the use of strut allograft to locking plate fixation alone. Favourable results of FSA group were seen in patient-reported outcome measures (PROMs), visual analogue scale (VAS) scores, neck-shaft angle integrity and rate of complications [34–37]. Bone quality and social independence can serve as indicators of physiologic age, which is more important than chronologic age when weighing treatment options. Social independence has even been shown to be a more reliable outcome predictor, than chronological age [22].

4.6 Locking plates vs intramedullary nails

Other than low local bone density, factors that promote failure of fixation and impair functional outcome are known to be avascular necrosis of the humeral head, residual varus displacement, nonanatomic reduction and insufficient restoration of the medial column [12]. Regarding those factors, there is still no known advantage of one implant over the other. A systematic review and meta-analysis have been done by Sun Qi *et al*, [38] to address this question. A comprehensive search of all major scientific databases has been conducted in 2017. After incorporating 13 comparative trials with 952 patients, a significantly higher penetration rate (relative risk (RR) = 1.75; 95% CI, 1.11–2.77; $p = 0.02$), and a significantly greater external rotation (mean deviation (MD) = 9.67; 95% CI, 4.22–15.12; $p = 0.0005$) were observed in the locking plate group compared with the intramedullary nail group. Constant-Murley scores, DASH scores and total complication rates were comparable between the two groups. There were also no significant differences in VAS scores, forward elevation, and other complications. Conclusions were given, that both osteosynthetic materials have similar performance in terms of functional scores and total complication rates. No superior treatment was suggested between locking plates and intramedullary nails for displaced proximal humeral fractures [38].

4.7 Arthroplasty

Primary arthroplasty has a role in individuals, who sustain complex fractures, where an adequate reduction and stable fixation of multi-part fractures, cannot be achieved. Also, factors known to be predictors of avascular humeral head necrosis [39] (short metaphyseal head extension (<8 mm), disruption of medial periosteal hinge, fracture through anatomical neck with shell-like head fragment) and non-reconstructable head-split fractures, can serve as objective indicators for arthroplasty. Patients in our cohort of 3- and 4-part fractures, who presented later as AVN, had at least one of the above-mentioned factors. However, years were not comparable due to short follow-up time after 2020 and some complications, such as AVN, might not come to light yet.

We distinguish between three common types of shoulder fracture arthroplasty: hemiarthroplasty (HA), total anatomic shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA).

HA is a replacement of metaphyseal humeral bone (fracture parts), with extirpation of the native humeral head. Humeral canal and the two tuberosities are prepared to fit the prosthesis. It is much more commonly used in younger patients, then in elderly. Still, it remains a viable option because of two reasons: first, hemiarthroplasty avoids complications, connected to glenoid component (*e.g.*, loosening, polyethylene wear / erosion, malposition, luxation). Second, it can be converted to a total shoulder arthroplasty, should that be required (native glenoid erosion, deltoid fatigue, revision operations) [40]. However, there are reasons why hemiarthroplasty is amenable only for a narrow group of elderly patients. The success of HA depends on a functional rotator cuff [41] and tuberosity healing [42]. Its complication rates are high; tuberosity-pull off, resorption and malposition of components are just some of the reasons why PROMs are low in comparison to nonoperative treatment, OS or RSA. Solberg *et al.* [42] retrospectively analysed data of 122 consecutive patients with 3- and 4-part proximal humerus fractures, between years 2002 and 2005. Thirty-eight patients, surgically treated with locking plates have been compared to forty-eight patients, who had undergone HA. After a minimum of 2 years follow-up, mean Constant-Murley score at final follow-up was significantly better in the locked-plate group.

(68.6 ± 9.5) than in HA group (60.6 ± 5.9); $p < 0.001$ [42]. We ourselves tend to fix a complex fracture, if the following criteria are met: functioning rotator cuff muscles, acceptable bone stock or bone density, absence of head-split fracture or any other of Hertel's criteria for predicting avascular necrosis. If we encounter some of these findings intraoperatively, or if anatomic reduction and stable fixation is not possible, we can convert our primary treatment strategy to arthroplasty. There is an ongoing increase in the use of RSA compared to HA [5, 14, 23, 24]. In our series of patients with 3- and 4-part fractures, we only had 2 patients with HA in the year 2015, and 52 patients with RSA (refer to subsection 3.5). We should however stress, that HA still has its role in patients younger than 65 years of age, who were not eligible for the purposes of this study. Sebastia-Forcada *et al.* [43] performed a randomised study comparing results of HA and RSA treatment in complex 3- and 4-part fractures, in patients over 70 years of age. RSA group at a mean follow-up of 28.5 months had a significantly better University of California of Los Angeles (UCLA) scores (29.1 *vs.* 21.1), Constant-Murley scores (56.1 *vs.* 40.0) and DASH scores (17 *vs.* 29); $p = 0.001$. RSA group was also better in anteflexion (112.9° *vs.* 78.7°) and abduction (112.9° *vs.* 78.7°) ($p = 0.001$). Significantly worse functional outcomes were observed in HA group with patients, who had tuberosity failure (avulsion, resorption). 19% of HA patients had revision surgeries with conversion to RSA.

RSA is a good alternative for patients with complex humeral fractures with rotator cuff deficiency or glenohumeral arthrosis, where an anatomic reduction and stable fixation is not possible. Austin *et al.* [44] reviewed 15 studies in a level III systematic review and meta-analysis. Population involved were elderly patients (over 65 years of age) with a proximal humeral fracture and a minimum follow-up of 6 months, who were treated either by HA (n = 492) or RSA (n = 421). Patients, who had RSA demonstrated significantly less pain ($p < 0.001$), better outcome scores ($p < 0.001$), and more forward flexion ($p < 0.001$) compared with those who had HA. Another major advantage of RSA has been implied by a significantly increased risk of all-cause reoperations in HA group ($p = 0.02$) [44]. Although function after RSA is less dependent on tuberosity healing than in HA, advantages in tuberosity union are noticeable. Gallinet *et al.* [45] demonstrated in a multicentre review of 420 patients, that patients with tuberosity union had a significantly better Constant-Murley score ($p = 0.004$), increased range of mobility in anteflexion ($p = 0.0001$) and external rotation ($p = 0.0001$), than patients with tuberosity nonunion [45]. Other studies have shown better scores as well, in better external rotation, subjective shoulder value (SSV) and better anteflexion, with tuberosity union [46–48].

What if these complex, non-reconstructable fractures with poor bone stock, would be left without surgery altogether? Lopiz *et al.* [49] recently compared nonoperative treatment of 3- and 4-part fractures in elderly patients with RSA, in a prospective randomised controlled trial. Primary objective was to compare pain and function after one year. Nonoperative group comprised of prospectively followed 30 patients and RSA group of 29. None of the standardised PROMs showed significant differences (Constant-Murley score: p = 0.071, DASH score: p = 0.075), but were a little better in favour of RSA group. VAS scores were significantly lower in RSA group (1.6 *vs.* 0.9; p = 0.011). The study demonstrated minimal benefits of RSA compared to nonoperative treatment for displaced 3- and 4-part fractures in the elderly. At short term follow-up, the main advantage of RSA appeared to be less pain perception [49]. Other authors have come to similar conclusions. Chivot *et al.* [50] concluded, that RSA does bring some significantly better functional results (Constant score 82.1% *vs.* 76.8%; p = 0.03), but clinical difference was relatively small, and this solution should only be proposed to patients who have a significant functional demand.

5. Conclusion

Regardless of the operative technique selected, there is evidence to suggest, that in elderly, operative and conservative treatment of complex 3- and 4-part humeral fractures, result in similar patient-reported and functional outcomes. Since no clear advantage of one over the other has yet been proven, factors, such as surgeon experience as well as quality and maintenance of the reduction with their impact on functional outcomes, should be further investigated. Patient factors, such as activity level, functional demands in daily life, independence, occupation, and comorbidities, play an important role in decision making. X-ray criteria are thus just guidance tools and not primary decision-making factors. Another factor that is proving to be an important one for a good surgical outcome, is bone quality. For geriatric patients, current evidence has demonstrated that RSA offers predictable functional outcomes, with a favourable complication profile. Definitive choice of treatment thus remains a multifactorial, patient-individualized, and surgeon-specific decision.

6. Limitations of our study

Limitations of our study, due to retrospective gathering of data, are numerous. First, we would like to stress, that each year was reviewed by a different surgeon, hence the interpretation, including division into partition groups, was subjective. Although we analysed only more complex three- and four-part fractures, we did not differ between fractures known to have a relatively poor prognosis (*e.g.*, fracture-dislocations) and fractures with more favourable outcomes (*e.g.*, valgus impacted fractures). Divisions into sub-groups should therefore be made for further analysis. Second, available data was poor in content, and we did not have any standardised questionnaire available for reviewing. Measurements of mobility are thus not exact and could be subjectively assessed by each treating surgeon. We didn't have much of pre-injury history data regarding mobility and functional status, as well as comorbidity level, occupational status, independence, and functional demands information, in majority of patients. Also, we acknowledge the fact, that at least one-year of follow-up should be available for functional assessment, hence three months minimum period might not reflect the true end-rehabilitation mobility state. Third, the COVID pandemic situation caused us a lot of problems in standard follow-up schedule in the last two years (2020, 2021), so a portion of patients (estimated at about 20–30%), might not have the final results in mobility, because the last check-up in year 2020 was done by phone call. Last, we would like to emphasise, that not enough time has passed from 2019 and 2020, so the degree of complications and rate of revision surgeries could not be correctly analysed and compared to 2015. This meaningful information for success in treatment is therefore missing.

AUTHOR CONTRIBUTIONS

MA, LK—designed the research study; RB, LH and MA—gathered the data and reviewed radiographs and ambulatory notes; RL—made the statistical analysis; MC, FŠ, LK—reviewed the final manuscript and suggested changes; MA—wrote the article.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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