

Intramedullary nailing of displaced four-part fractures of the proximal humerus

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ARTICLE INFO

Article history:

Accepted 25 June 2019

Keywords:

Four-Part fracture
Intramedullary nailing
Proximal humerus
Multiloc PHN

ABSTRACT

Background: Intramedullary nailing is already established technique for the treatment of two and three-part fractures of proximal humerus. The aim of the study was to prospectively evaluate the efficacy and functional outcome after treatment of four-part fractures of proximal humerus with Multiloc proximal humeral nail.

Design: prospective monocentric cohort study.

Setting: single level 1 traumacenter.

Materials and Methods: From February 2011 to March 2016, 40 patients with displaced four-part proximal humeral fractures were treated with intramedullary nail inserted through anterolateral approach. Minimum one year follow up completed 35 patients and were involved into the study.

Results: After mean follow up period of 25.8 months 29 of 35 fractures healed. Average absolute Constant score in all 35 patients reached 57.7 points, relative side related Constants score 66.8% of contralateral extremity. Together there were 20 complications. in 6 cases (17%) developed complete avascular necrosis of the head. One deep infection was treated by implantation of antibiotic cement discs. Twelve secondary surgeries were performed, mostly for avascular necrosis development. Function and pain were significantly influenced by the quality of fracture reduction ($p < 0.05$) and development of complete AVN ($p = 0.001$). Group of 29 patients without AVN reached relative Constant score 73% of contralateral extremity.

Conclusions: Intramedullary nailing can be used as possible fixation technique for the treatment of four-part fractures of proximal humerus. In experienced hands provides nailing osteosynthesis similar results as reconstruction with locking plates. Appropriate reduction of fracture fragments is the key for good functional result.

Level of evidence: Level 2b – monocentric prospective cohort study.

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Introduction

Consensus on the treatment strategy of displaced 4-part proximal humeral fractures is still in the focus of the interest. Current strategy prefers individual approach according to biological age and fracture patterns. In younger patients, reduction and stable fixation with locking plates is recommended in all fractures capable for reconstruction, in active elderly patients, reverse shoulder arthroplasty is more frequent because of shorter physiotherapy and one-shot surgery. Results of the studies are

influenced by inclusion criteria for reconstruction strategy and quality of surgery performance, especially appropriate reduction. The use of intramedullary nails has spread in last years from diaphyseal parts of long bones to the bone ends and anatomically designed nails were developed for proximal humerus too. First were nails used in this area for the fractures of the surgical neck, with increasing experience indications were extended to three and four-part fractures [1–4]. Interpretation of current literature is difficult because of often heterogeneity of involved fractures and low numbers of patients with four-part fractures [5].

The aim of the prospective study was to evaluate clinical results of intramedullary nailing of displaced four-part fractures and analyse influence of the reduction quality on the functional outcome. Our hypothesis was that better reduction will lead to better functional outcome.

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To our knowledge this study represents the largest cohort of patients with 4-part displaced fracture treated by the intramedullary nail.

Material and methods

Ethics

The study was approved by the Institutional Review Board of Hospital.

Setting

Level II - single Level I trauma centre prospective cohort study.

Patients and methods

Inclusion criteria for involving into the study were: adult patient (18–90) with displaced four-part fracture of the humeral head according to Neer classification [6], treated by ORIF with intramedullary nail Multiloc PHN (DePuy Synthes, USA) from February 2011 to March 2016. Exclusion criteria were – bilateral fracture, pathologic fracture, previous injury in opposite shoulder with restriction of function, posttraumatic brachial plexus injury or peripheral nerve palsy. From 186 patients treated in mentioned period for proximal humeral fracture by Multiloc Nail in the department, inclusion setting filled out 40 patients.

Interventions

After X-ray with diagnose or suspicion of four-part fracture CT of injured proximal humerus with 2D and 3D reconstructions was performed. From CT 3D definitive decision about fracture type was made. All fractures with technical possibility of reduction and fixation were indicated for reconstructive strategy, this option was decided by 2 most experienced surgeons (author, senior author). Patients absolved detailed interview about treatment possibilities. Ability for physiotherapy was checked. To all patients with ability for physiotherapy open reduction and stable osteosynthesis with intramedullary nail was recommended. Patients who decided for operative treatment were admitted to the department. Operation was planned for comfort situation during the regular operative day, surgeon was chosen according to the difficulty of the fracture.

Surgical procedure

Patients were operated in beach-chair position through an anterolateral deltoid split approach with arm in retroversion. Incision started 1–2 cm medially from lateral end of acromion in 45-degree plane and length was 5–7 cm, preserving axillary nerve in distal pole of the approach. Reduction of head fragments was performed individually according to the fracture patterns, with K wires used in joystick technique, bone hooks and sutures. Reduced fragments of the head were transfixed together with K-wires 1.5–2.2 mm and some of them were then used as joysticks too. With support of joysticks head complex was manipulated to ideal position regarding the glenoid and first after that 2–3 cm long longitudinal incision into the rotator cuff was performed, parallel with cuff fibers. In cases, where rotator cuff was torn and localized approximately in the planned trepanation of the head, this rupture was used for approach. Optimal insertion point for the nail on the head was localized with X-ray control. Guiding K wire was inserted into the head, position of the wire was checked in two perpendicular planes. C arm was used from opposite side of the patient in horizontal plane. Head was then reamed and proximal humeral nail Multiloc PHN (DePuy Synthes, USA) was introduced into the

head. In all cases 160 x 8 mm nail was used. Together with reduction of neck component of the fracture, nail was introduced further into the diaphysis. Depth of insertion was adapted to the ideal position of proximal locking screws regarding fracture fragments, if the nail was too deep, the ideal depth bellow cartilage (2–3 mm) was extended by extension cap. Proximally maximum possible amount of locking screws was used, in majority of cases with one or two additional angular stable screws used in screw-in-screw technique. Distal locking by 2 screws was performed in all cases. Length of all locking screws was checked. Closure of rotator cuff was made by non-resorbable sutures. Lightening sutures from non-resorbable material were inserted into the rotator cuff and connected with holes in proximal locking screws for neutralization of the forces coming from rotator cuff muscles during physiotherapy. Suture was closed by layers.

Postoperative protocol, follow up

All patients prospectively underwent same postoperative physiotherapy protocol that emphasized early passive motion exercises. Isometric deltoid, biceps, and triceps strengthening exercises begun immediately after diminishing of major postoperative pain. Patients were fit with a sling and continued with maximum passive range of motion exercises for the first 6 weeks postoperatively. Then patients began active exercises in a formal physiotherapy program.

Patients were prospectively evaluated after 6,12,24 and 52 weeks after surgery. Qualified evaluator performed plain radiography and clinical evaluation of the shoulder motion. After involving of 40 patients into the study, all patients were invited for final follow-up after minimum of 12 months in period of February–March 2017. This final evaluation consisted of shoulder radiography, evaluation of active range of motion, subjective level of the pain using VAS 0–10 points and evaluation of absolute Constant-Murley score of injured shoulder (CS^{abs}) [7]. Side related relative Constant score (CS^{rel}) was calculated as relationship between CS^{abs} of injured and non-injured shoulder. In the event of a complication that resulted in salvage procedure (painful head necrosis development, failure of fixation), clinical dates from last follow-up before salvage procedure were used for the analysis.

Measurement of reduction quality

Quality of achieved reduction of the fracture was evaluated from intraoperative X-rays by two experienced surgeons by a measurement of residual distance and angle between main fracture fragments. For this purpose, the DICOM viewing software was used. According to achieved quality of reduction patients were divided into 3 groups, rated as 1 = excellent quality of reduction - with residual displacement between fragments of the head, tuberosities and shaft of less than 5 mm or less than 20-degree of angular displacement, 2 = moderate (5–10 mm between fragments or 20–40 residual angular displacement) and 3 = poor (more than 10 mm or 40-degree angular displacement). For submission into reduction quality group residual distance already between two fragments was a criterion. Strategy of measurement was described in previous study [4].

Follow-up X-rays were used to identify union and all complications - mal-union, signs of avascular necrosis, resorption of the greater tuberosity or reduction/fixation failure.

In this study, union was defined as the patient reporting either no shoulder pain or only mild activity-related pain and having no loss of the initial fracture reduction or evidence of implant-loosening or breakage, along with evidence of external callous formation. The presence of pain due to some other obvious cause such as protruding screws or adhesive capsulitis did not exclude

the diagnosis of union. Cases with resorption and collapse of the head followed by protrusion of the implant into the glenohumeral joint were rated as complete osteonecrosis. Cases with partial resorption of the head which did not lead to head collapse and in which the proximal end of the nail remained underneath the cartilage were rated as partial necrosis. Non-union was defined as a failure of union to occur within 6 months post fixation. Deep infection was defined as an infection deep to the deltopectoral interval.

Statistics

Statistical analysis was performed by software MS Excel 2016. Continuous variables were described using means, standard deviations and ranges. Categorical variables were tabulated with absolute and relative frequencies. Pearson's correlation was used to compute associations between variables. The matched numerical outcome was measured using one-way analysis of variance (ANOVA) for functional outcome in multiple groups. Chi-square test was used for analysis of relationship between reduction quality and head necrosis development. A p value < 0.05 was considered significant.

Results

Participants

Final clinical follow-up completed 35 patients (87%) from original cohort of 40 patients. Five patients were lost - 1 patient died, 2 patients refused participation due to long traveling, 2 were not reached. Definitive cohort of 35 patients was analysed. Average follow-up was 256 weeks (SD, 19.3; range, 6–77)

Descriptive data

Of 35 patients with average age 62.3 years (SD, 12.7; range, 35–81) there were 20 females, mean age 69.9 years (SD, 7.0; range, 59–81) and 15 males, mean age 52.1 years (SD, 11.5; range, 35–75) in the time of operation. Average time from injury to surgery was 3.8 days (SD, 3.5; range, 1–18), average length of the procedure 99 min (SD, 26.4; range, 60–145). Operations were performed by 8 surgeons, 29 of 35 operations were done by 2 most experienced

surgeons. In 22 cases was achieved excellent reduction, in 10 cases moderate, poor reduction was observed in 3 cases.

Outcome data

Of 35 fractures 29 healed in average 8.6 (range, 6–12) weeks, in 6 cases developed complete avascular necrosis of the head. Average absolute Constant score of all patients was 57.7 (SD, 22.4; range, 16–95), male/female 64.9/52.3; relative side related Constants score 66.8% (range, 18%–105%) of opposite extremity (male/female 66.0%/68.00%). Average level of the pain was 3.3 from 10 points scale. Function and pain were influenced by achieved quality of reduction and development of complete AVN. CS^{abs}/CS^{rel} in the group of excellent reduction achieved 62.6 pts/73.4% comparing with the group of moderate (54.0 pts/60.4%) and poor reduction (34.0 pts/40.6%), (ANOVA, $p = 0.046$), Fig. 1. In the group of 29 patients where head necrosis didn't develop average CS^{abs}/CS^{rel} reached 63.1 pts/72.0% comparing with group of 6 complete head necrosis, where score dropped to 31.6 pts/36.6% (statistically significant, Chi-square test, $P = 0.001$). The outcome was not influenced by age, gender or delay to the surgery.

Data of all patients with results and complications in Table 1, documentation of two patients in Figs. 2 and 3.

Complications

In 35 patients there were together 20 complications until final follow-up. Most frequent complications were head necrosis and failure of fixation. Complete head necrosis occurred in 6 cases (17.1%), partial necrosis of the head in 3 cases, resorption of the greater tuberosity in 5 cases. Loss of reduction occurred in 4 cases – 2 times greater tuberosity migration proximally, 1 times greater tuberosity dorsally, 1x varus angulation development. One deep infection was treated by implantation of antibiotic cement discs with gentamicin-vancomycin, removed after 4 weeks.

Twelve secondary surgeries were performed – 4 times reverse total shoulder arthroplasty (once for AVN, 3 times for loss of function of rotator cuff and migration of humeral head proximally), 2 times hemiarthroplasty in the cases of AVN, 5 times removal of the implants. Once was applied implantation and removal of ATB cement discs.



Fig. 1. Influence of reduction quality on relative Constant score of opposite extremity.

Table 1
Descriptive data, outcomes and complications of all 35 patients.

P	Gender	Age	Time to operation (days)	Duration of surgery (min)	Quality of reduction	Follow up (months)	Elevation injured	Relative elevation %	CS abs pts	CS rel %	Pain VAS 0–10	Complication	Secondary surgery
1	F	81	1	75	1	12	90	56.25%	34	45%	4	complete AVN	
2	F	63	7	85	1	13	170	100.00%	78	86%	3		
3	M	75	7	60	1	12	110	64.71%	62	70%	3		
4	F	66	2	80	1	33	130	100.00%	63	105%	5		
5	F	73	5	80	1	12	90	100.00%	29	81%	8	loss of reduction + infection	ATB spacer, rTSA
6	F	60	1	105	1	27	140	82.35%	69	78%	1		
7	M	64	18	75	1	10	80	53.33%	29	32%	7	complete AVN	HA
8	M	42	3	95	1	24	120	75.00%	79	86%	0		
9	M	49	2	120	1	36	150	85.71%	86	88%	0		
10	F	63	1	105	1	12	160	94.12%	81	90%	1		
11	M	35	5	95	1	77	170	97.14%	95	95%	1		
12	M	51	1	90	1	26	145	85.29%	77	77%	3		
13	F	78	1	85	1	10	110	73.33%	50	65%	3		
14	M	43	1	145	1	60	95	55.88%	49	50%	4	resorption of greater tuberosity	ASC + removal
15	M	64	3	130	1	68	140	87.50%	73	78%	4		
16	M	44	7	90	1	58	100	62.50%	63	70%	0	partial AVN	
17	F	79	2	90	1	35	150	100.00%	81	100%	1		
18	F	61	5	100	1	12	80	51.61%	26	30%	6	complete AVN	metal removal
19	F	71	1	65	1	56	175	100.00%	82	98%	0		
20	M	56	2	120	1	54	105	63.64%	62	66%	2	resorption of greater tuberosity	metal removal
21	F	81	3	105	1	18	80	55.17%	37	51%	3	partial AVN	
22	M	68	12	90	1	12	160	96.97%	73	73%	1	loss of reduction	
23	F	66	2	75	2	13	160	94.12%	86	97%	0		
24	M	55	1	105	2	13	30	17.65%	24	25%	6	complete AVN	rTSA
25	F	72	0	75	2	14	40	27.59%	32	42%	6	resorption of greater tuberosity	rTSA
26	M	51	3	75	2	51	115	71.88%	79	82%	0	partial AVN	
27	M	51	5	200	2	11	90	56.25%	37	39%	6	complete AVN	HA
28	M	34	4	105	2	12	170	97.14%	86	88%	0		
29	F	63	4	120	2	12	145	85.29%	69	78%	3	loss of reduction	
30	F	69	4	95	2	19	90	60.00%	40	48%	5	complete AVN	metal removal
31	F	71	2	140	2	26	140	87.50%	59	69%	5		
32	F	76	9	90	2	12	80	51.61%	28	35%	7	loss of reduction	
33	F	59	2	120	3	12	45	28.13%	16	19%	8	migration of the head proximally	rTSA
34	F	78	4	95	3	12	75	46.88%	36	41%	4	resorption of greater tuberosity	
35	F	70	3	80	3	18	85	68.00%	50	62%	5	nail protrusion proximally	metal removal
Mean		62.3	3.8	98.9	1.46	25.8	114.7	72.4%	57.7	66.8%	3.3	20	12

P:patient, Quality of reduction - 1: excellent, 2: moderate, 3: poor, AVN: avascular necrosis. Secondary surgery: rTSA: reverse total shoulder arthroplasty, HA: hemiarthroplasty, ASC: arthroscopy.

Documentation of patient with failure of fixation and salvage with rTSA on Fig. 4.

Discussion

Our study yielded important findings. First, functional result was significantly influenced by quality of achieved reduction. Second, if head necrosis developed, clinical outcome dramatically dropped.

ORIF studies concentrating selectively on of 4-part fractures of proximal humerus are relatively rare instead of growing interest in this area. Especially nailing studies are really exceptional [5]. Comparing of results is complicated due to different approach in the treatment of these fractures. Ratio between fractures which are indicated for reconstruction and for replacement is different in each department and differs according to the age of the patient too. Indication for replacement could be elderly patient, probably ischemic head and other factors. In our department were in mentioned period indicated for primarily replacement 6 patients with 4-part fracture, comparing with 52 patients indicated in same

time for reconstruction (12 treated by Targon pH nail). As more difficult fractures are indicated for reconstruction, higher number of complications can be anticipated, especially rate of head necrosis. Instead of that, functional results and complication numbers in our study are comparable with results of current studies used different fixation techniques.

Outcome

Average CS^{abs} and CS^{rel} of all our patients were 57.7/66.8%. Wong analysed 14 nailing studies with 448 fractures, but there were only 27 clinically evaluated 4-part fractures, average CS reached 63.6 (SD, 19.9) [5]. Study with highest number of four-part fractures involved in this meta-analysis published Gradl 2007, who collected 17 patients with 4-part fracture [8]. Average CS in his study was 60.7 (SD,23.2), CS^{rel} 65.7% (SD,23.8). In our study 5 years ago, we published experience with same implant as Gradl, intramedullary nail Targon PH. In this study, we evaluated 38 patients with 4-part fracture in average age 62.7 years, with average CS 63.8 (SD, 25.4), CS^{rel} 73.2% (SD,26.5) [4].



Fig. 2. (a–e) Patient Nr.19: female, 71 years old. (a) injury x-rays. (b) CT 3D reconstruction. (c) osteosynthesis with Multiloc PHN (DePuy Synthes) from OP theater. (d) x-rays of healed fracture after 56 months. (e) clinical outcome after 56 months - CSabs 82pts, CSrel 98%.

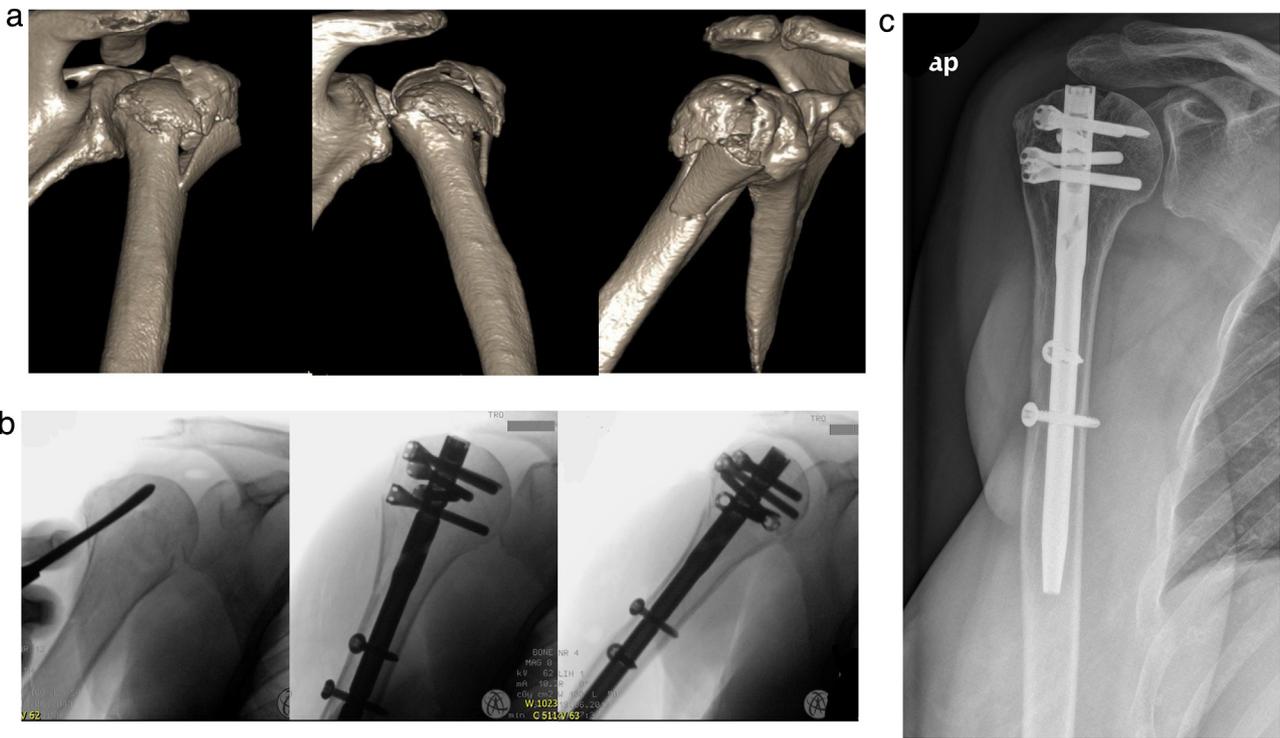


Fig. 3. (a–c) Patient Nr.10: female, 63 years old. (a) injury CT 3D. (b) reduction and osteosynthesis with Multiloc PHN. (c) x-ray with healed fracture after 12 months, clinical outcome after 12 months - CS^{abs} 81pts, CS^{rel} 90%.

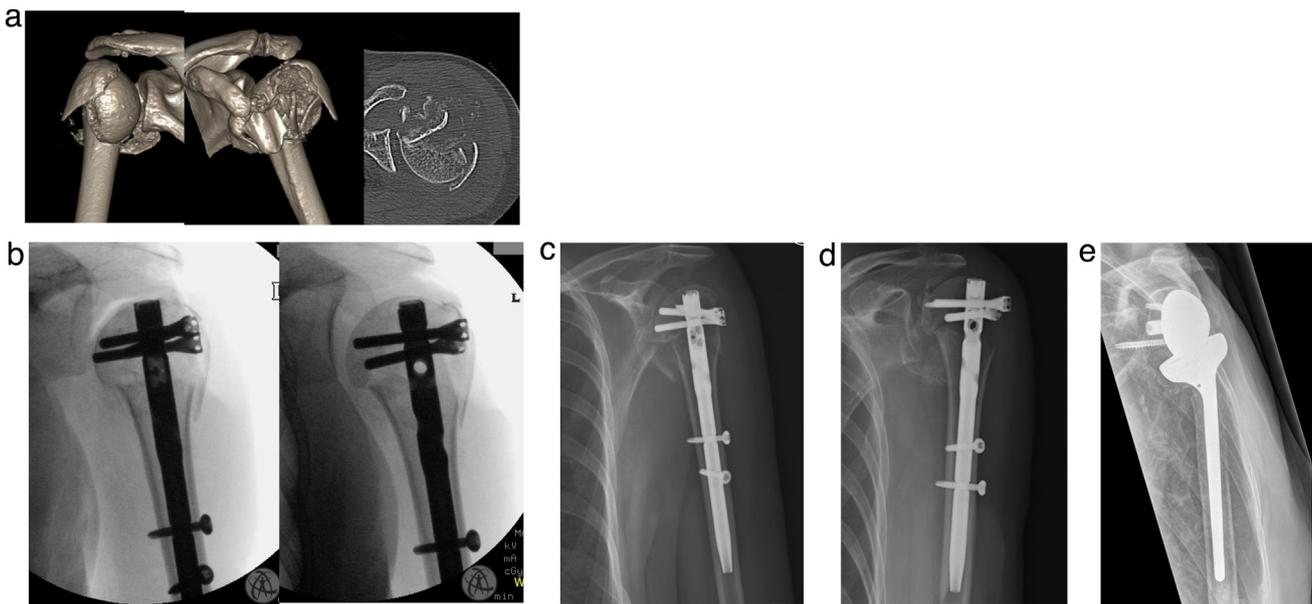


Fig. 4. (a–e) Patient Nr.5: female, 73 years old. (a) injury CT 3D and 2D. (b) reduction and osteosynthesis with Multiloc PHN (DePuy Synthes) from OP theater. (c) complication - failure of fixation 6 weeks after osteosynthesis, migration of greater tuberosity, conservative treatment of complication. (d) months after osteosynthesis, painful migration of humerus proximally, (e) salvage with rTSA DePuy Synthes, x-ray after 2 years.

Plating cohorts are greater, but problems with outcome and complications for different groups of fractures is present too. Sproul analysed 12 studies with locking plates treatment of proximal humeral fractures. In 514 patients, 109 four-part fractures were analysed [9]. Average Constant score reached 66pts (57–79). This is higher than our results. It can be influenced by the fact, that we indicated for the reconstruction

all fractures technically capable for reconstruction. In study of Greiner reached CS 56.4 (SD, 12.9) for 4-part fractures [10]. Patients with 4-part fracture treated by Philos plate in study of Solberg reached in average 64.7 points [11]. Sohn treated in prospective study 11 4-part fractures with MIPO/open plating, their mean CS was 63.2 for ORIF and 62.2 for MIPO technique [12].

Complications

Avascular necrosis

The most frequent complication in our cohort was head necrosis, which occurred in 9 cases (25.7%). Complete head necrosis then in 6 cases (17.1%). Rate of avascular necrosis can be compared only with studies, where complications are divided selectively to the fracture type. Gradl observed in 17 four-part fractures 2 head necrosis, which is lower than our study. Reason could be only one-year follow up in his study, head necrosis can develop up to 3 years after injury. Indication criteria for reconstruction/replacement of the fracture strongly influences rate of this type of complication. Other nailing studies have too small numbers of fractures or complications are not calculated selectively for 4-part fractures.

Plating studies describe similar rates of head necrosis as our study – Erasmo 2014 injury 10/35 (28.5%), Helwig observed in his study 5 cases of head necrosis in 11 four-part fractures, in study of Greiner developed AVN in 3 cases from 9 four-part fractures (33%). Gerber et al. reported a rate of partial or total humeral head necrosis of 35% after different internal fixation methods (with a majority of minimally invasive fixation procedures) of 3-part and 4-part fractures after a follow-up period of 63 months. Sohn observed in his 11 fractures together 11 complications, interestingly no head necrosis [12].

In our study, development of complete AVN decreases function of the shoulder. When cases with complete AVN are excluded from analysis, average CS^{abs} rose from 58.3 pts to 63.1 pts (CS^{rel} from 66.8% to 72.0%). Average CS^{abs}/CS^{rel} in the group where AVN developed failed to 31.6 pts/36.6%. This impairment is statistically significant (Chi-square, $p < 0.05$).

Revisions rate and influence of this complication on decision strategy

Rate of revision procedures was 30% in our cohort. This could be problematic in the group of elderly patients, where repeated surgeries could be problematic. Decision between all types of treatment (reconstruction, replacement or conservative strategy) should be very carefully done and benefits of strategies discussed preoperatively with each individual patient. Criteria, which support reconstructive strategy, are especially age below 65, active patient, fulfilled Hertel's criteria for better vascular supply, good bone stock and patient's ability for enough long physiotherapy. Interesting is comparing of functional results and complication rate between the groups of patients under and over 70 years. In the group of 24 patients younger than 70 years relative elevation was 73.7% and there were together 13 complications (54%) with 9 revision surgeries (37.5%) from them 3 arthroplasties. In 11 patients above 70 with average elevation 72.4% there were together 6 complications (55%) with 3 revision surgeries (27%) and 2 arthroplasties. Although functional results and complication rate in both groups are similar, for elderly patients one shot surgery should be preferred. Therefore, as patient's age is growing, joint replacement or conservative strategy should be more preferred.

Relationship reduction-functional result

Influence of reduction quality on the functional result was already observed and many studies report worsening of outcome in malreduced or malunited fractures [13–16]. Our study underlines these findings. Appropriate reduction led in our study to significantly better functional result. Helwig found relationship between poor score and poor anatomical reduction of the fracture [17].

Strengths and limitations

Our study shows borders of intramedullary technique in this area. Similar results can be repeated only in experienced hands,

majority of procedures were in our study done by 2 most experienced doctors. Surgeons should learn nailing in more simple fractures and first after getting experience and learning basic steps move to the group of four-part fractures. In fact, this is not problem only of nailing but generally of individual ability for reduction of most complicated fractures of proximal humerus. Disadvantage of the study could be different length of follow-up, where in some patients it is only little bit more than 12 months. On the other side, functional result in this time is already definitive and probability of head necrosis development is lesser in second and third year. Limitation could be also different time from the injury to the surgery, which varies from 1 to 18 days and can influence avascular necrosis development, although it was not confirmed in other studies yet. Further studies on greater cohorts of patients are necessary for statistical analysis of this fact.

Power of our study is number of treated fractures in one department, involvement of all fractures with technical possibility for reconstruction into the study, high part of clinically followed patients and generalizability of the strategy of the treatment, where appropriate reduction of these fractures is prerequisite for final good outcome.

Conclusion

Intramedullary nailing can be used for the treatment of displaced four-part fractures of proximal humerus. In experienced hands provides nailing technique similar results as reconstruction of these fractures with locking plates. Reduction of fracture fragments is important for functional result. If complete head necrosis develops, function of the shoulder gets dramatically worse.

Conflicts of interest and sources of funding

There was no conflict of interest and sources of funding.

Declaration of Competing Interest

The authors, their immediate families, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article. No outside funding or grants were received in preparation or editing of this manuscript.

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