TRAUMA SURGERY

Functional improvement is sustained following anatomical and reverse shoulder arthroplasty for fracture sequelae: a registry-based analysis

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Abstract

Introduction Shoulder arthroplasty for proximal humerus fracture sequelae is known to provide significant patient improvement, yet this outcome varies with time, prosthesis type, and fracture sequelae. We outline the expected course of postoperative shoulder pain and function in patients with anatomical (ASA) or reverse (RSA) shoulder arthroplasty following different fracture sequelae.

Materials and methods Of 111 consecutive patients from our local shoulder arthroplasty registry, 32 underwent ASA for Boileau type 1 sequelae and 77 RSA patients were identified with Boileau types I, III, and IV. By 5 year post-surgery, there were 72 patients available. All patients underwent standardised ASA or RSA procedures with anatomical (Promos Standard; Lima SMR™; Arthrex Eclipse™; Univers™ II) or reverse prostheses (Promos Reverse®; Lima SMR™ Reverse; Univers Revers™; Aequalis® Reversed). Range of motion, Constant–Murley, Disability of the Arm, Shoulder and Hand (DASH), and Shoulder Pain and Disability Index (SPADI) scores were compared at 6, 12, 24, and 60 months postoperatively. We used generalised linear mixed models or random-effects ordered logistic regression to investigate postoperative changes of outcome parameters from baseline to follow-up time points for each group as well as for group comparisons.

Results Range of motion and clinical scores improved until 24 months postoperatively and did not deteriorate thereafter, except for internal rotation of Boileau type III and IV patients and external rotation of RSA patients with type I and IV sequelae. At all follow-ups, ASA patients with Boileau type I sequelae had significantly better internal and external rotation versus patients with RSA and/or other Boileau types ($p < 0.001$), while Constant, DASH, and SPADI scores were not significantly different between groups.

Conclusion In humeral fracture sequelae, ASA and RSA lead to sustained clinical improvements. Surgeons may primarily consider implantation of ASA in type I sequelae.

Keywords Shoulder · Arthroplasty · Shoulder replacement · Proximal humerus fracture · Post-traumatic sequelae

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Introduction

The incidence of proximal humerus fractures is increasing [1] and the treatment of complex fractures remains difficult. Non-operative treatment [2], incomplete surgical

reduction [3], or secondary fracture displacement [4] can result in various types of fracture sequelae [5], which may lead to pain and loss of shoulder function. Fracture malunion can be treated using joint-preserving techniques [5–7], but shoulder arthroplasty may be indicated in severe malunion, post-traumatic avascular necrosis, and osteoarthritis as well as chronic glenohumeral joint dislocation [8]. Shoulder arthroplasty in patients with post-traumatic fracture sequelae remains nonetheless challenging, with less predictable outcome and high rates of complications [9] including dislocations, infections, and iatrogenic fractures [10, 11].

Indications and techniques for shoulder arthroplasty in fracture sequelae were streamlined since the development of the Boileau classification system [12, 13], which distinguishes between intracapsular sequelae with humeral head collapse or necrosis (type I), chronic unreducible glenohumeral dislocations (type II), extracapsular sequelae including surgical neck nonunion (type III), and greater tuberosity malunion (type IV). Anatomical shoulder arthroplasty (ASA) is recommended for types I and II sequelae with intact rotator cuff status [12], whereas reverse shoulder arthroplasty (RSA) is suggested for all type IV sequelae and type I patients with a deficient rotator cuff and/or chronic anterior dislocations [11, 12]. Several Level IV studies show significant clinical improvement with either ASA or RSA following fracture sequelae, yet only at isolated follow-up time points [14–19]. Of the few comparative studies [20, 21], none reported successive patient follow-up after ASA and RSA in fracture sequelae. Controversy regarding the appropriate arthroplasty type in surgical neck nonunions (type III) still exists [17], and the course of recovery following different fracture sequelae and arthroplasty types is essentially unknown. Therefore, our aim was to outline the expected course of postoperative shoulder pain and function in patients with anatomical (ASA) or reverse (RSA) shoulder arthroplasty following different fracture sequelae from prospectively collected patient data of our local registry. This comparative analysis was approved by the Cantonal Ethics Committee of Zurich (KEK-ZH Nr. 2014-0483) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Materials and methods

From March 2006 until June 2015, a total of 1,868 total shoulder arthroplasty procedures were performed at our institution and prospectively documented in a local shoulder arthroplasty registry. Registry patients are examined routinely before (i.e. baseline) and 6, 12, 24, and 60 months post-surgery.

We included patients who underwent shoulder arthroplasty following post-traumatic proximal humerus fracture sequelae. Patients with available baseline radiographs for Boileau classification and documented outcome scores at both baseline and 24-month follow-up examinations were selected. All patients provided written informed consent to use their clinical data for research purposes.

Standardised surgical procedures for ASA and RSA were applied. We used a deltopectoral approach with patients under general anesthesia in a beach chair position. Tenotomy or tenodesis of the long head of the biceps was performed in intact tendons. The subscapularis tendon was tenotomised and humeral head was exposed. For ASA procedures, we made an anatomical cut to resect the humeral head. Patients received either a stemmed (Promos Standard, Smith & Nephew Orthopedics AG, Rotkreuz, Switzerland; Lima SMR™, Lima Corporation S.p.a., Udine, Italy; or Univers™ II, Arthrex Swiss AG, Belp-Bern, Switzerland) or unstemmed shoulder arthroplasty system (Arthrex Eclipse™). The glenoid side was either left untreated (hemiarthroplasty [$n=10$]) or implanted with a cemented polyethylene component ($n=21$) or metal back ($n=3$). The subscapularis tendon was re-fixed in all ASA cases. In the case of RSA implantation with one of the following prostheses: Promos Reverse® (Smith & Nephew Orthopaedics AG, Rotkreuz, Switzerland); Lima SMR™ Reverse Modular Shoulder System (Lima Corporate S.p.a., Udine, Italy); Univers Revers™ (Arthrex Swiss AG, Belp-Bern, Switzerland); Aequalis® Reversed (Tornier AG, Cham, Switzerland), the humeral head was resected at an angle of 135°–155° depending on the specifications of each implant. The humerus was then reamed to receive an uncemented stem in 5–20° of retroversion. Following glenoid exposure, the baseplate was placed flush with the inferior rim of the glenoid and secured with an inferior and superior screw. The size and eccentricity of the glenosphere was based on preoperative templating and intraoperative trialling to minimize notching, and to ensure adequate stability and soft-tissue tensioning. Subscapularis repair was performed whenever possible at the end of the procedure.

Following ASA and RSA, shoulders were kept immobilized at night for 4 weeks. Patients followed a daily rehabilitation program of immediate passive and active-assisted exercises and strengthening exercises at 12 weeks postoperatively.

Preoperative anteroposterior and lateral radiographs of the affected shoulder were evaluated by a trained orthopedic surgeon (third author) to assess the type of fracture sequelae according to Boileau et al. [13]. Baseline rotator cuff integrity was assessed by ultrasound assessments or from MRI scans. Fatty infiltration of the rotator cuff muscles was assessed according to Goutallier [22] from all available MRI scans.

Patient-reported outcome was measured using the quick Disabilities of Arm, Shoulder and Hand score (qDASH)

[23] and Shoulder Pain and Disability Index (SPADI) survey [24]. At each follow-up, we assessed functional outcome using the Constant–Murley Score (CMS) [25] along with range of motion (ROM) measurements in flexion, abduction, internal rotation (Apley scratch test), and external rotation with the affected arm at the side. Shoulder strength by 90° abduction was also measured using a spring balance (Pesola AG, Baar, Switzerland). At the last follow-up, patients were asked if they would consider undergoing the same operation again. Revision operations were documented throughout the 60-month postoperative follow-up period.

Statistical analysis

Data were managed using REDCap [26] and analyzed with Stata version 14 (StataCorp LP, College Station, TX). Regarding individual patient data, patient groups were identified based on the Boileau classification and shoulder arthroplasty type. Baseline parameters were tabulated and compared between groups. Outcome parameters were tabulated per group at each examination time point. Missing outcome parameter values were replaced by multiple multivariate chained imputation [27] while considering patient age, gender, the American Society of Anesthesiologists Physical Status classification, rotator cuff integrity, patient group, and available outcome data. This approach provides valid estimates about the missing outcome values, and was considered more appropriate than ignoring them in the analysis as if they had occurred completely at random. Postoperative changes of outcome parameters from baseline to follow-up time points were investigated separately for each group using generalized linear mixed models or random-effects ordered logistic regression. Comparative analyses between groups were conducted using similar regression methods and included the respective baseline preoperative outcome values; the analyses were made with and without adjusting for the baseline variables of age and gender. We also conducted analyses on raw non-imputed data as part of a sensitivity analysis. Significance level was set at 0.05.

Results

One hundred and fifty-two shoulder arthroplasties were implanted in 151 patients for proximal humerus fracture sequelae excluding nine resurfacing shoulder arthroplasties (Fig. 1). Of 151 patients, 36 were excluded due to incomplete data at baseline ($n = 3$) and/or at the 2-year follow-up ($n = 33$). Four additional cases with insufficient baseline radiographs and one polytrauma patient with complete plexus palsy were also excluded. A resultant total of 111 patients with 111 shoulder arthroplasties were available for

Fig. 1 Clinical study patient selection flow diagram. *Constant–Murley (CMS), Shoulder Pain and Disability Index (SPADI), and quick Disabilities of Arm, Shoulder and Hand (qDASH) scores were all missing
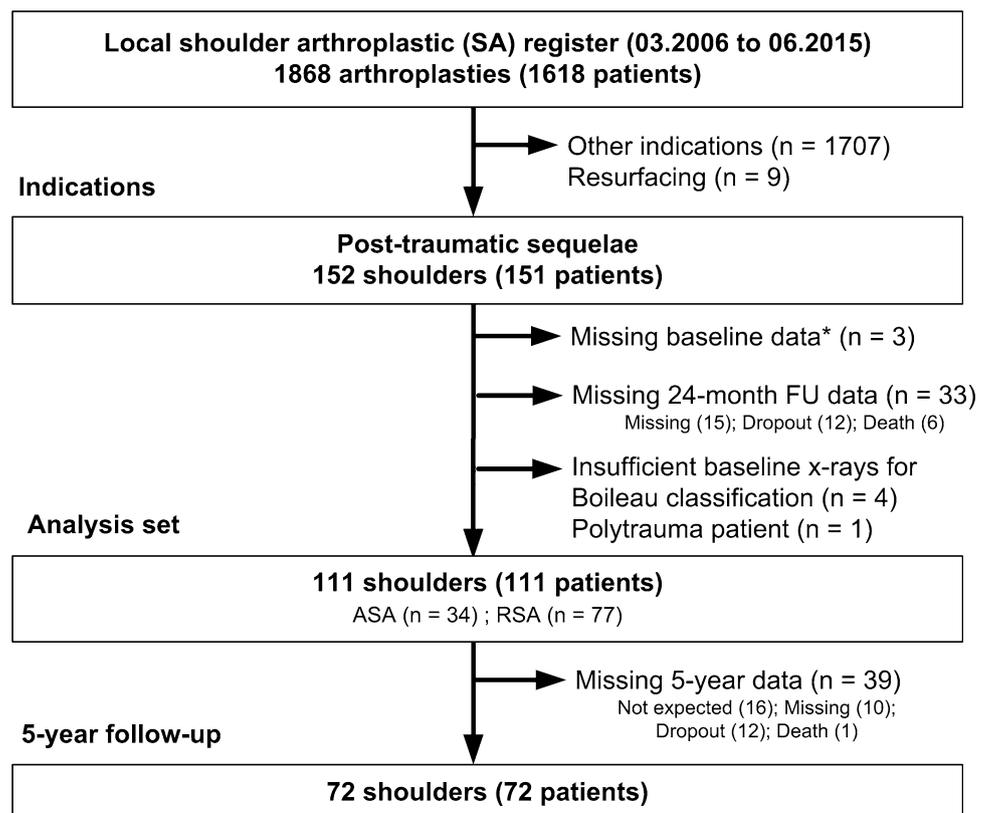
inclusion in our analysis, of whom 72 were followed until 5 years after surgery. The median (range) follow-up at 6, 12, and 24 months as well as 5 years post-surgery was 6 months (5–8.1), 11.9 months (10.1–15.1), 24 months (21.4–27.3), and 5 years (4.3–5.7), respectively.

The selected patients were grouped according to their Boileau classification and prosthesis type (Table 1). Thirty-two ASAs and 40 RSAs were implanted in patients with type I fracture sequelae. There were only single ASA cases for Boileau type II (72-year-old female) and type IV (38-year-old female) sequelae each with intact rotator cuff integrity. Additional RSAs were implanted in 14 and 23 patients with Boileau type III and IV sequelae, respectively. Patients with ASA and type I sequelae appeared younger and healthier than those in the other groups, and were more frequently male and without rotator cuff lesions. In addition, Type I sequelae patients had greater ROM and higher baseline functional scores, and a higher proportion reached the lumbosacral junction in the Apley scratch test compared to type III and IV sequelae patients. The level of pain and lack of shoulder strength was similar across all groups.

Our four patient groups significantly improved regarding all clinical and patient-reported outcome parameters (Figs. 2, 3; $p < 0.044$) except for the following: internal rotation for Boileau type III and IV patients ($p > 0.054$); external rotation in 0° abduction for Boileau type I and IV patients receiving a RSA ($p > 0.204$); and shoulder pain level for Boileau type III patients ($p = 0.166$).

Overall, there were no significant differences between the groups at the follow-up examinations for ROM in flexion and abduction, and shoulder strength in abduction after baseline value adjustments (e-Supplement 1; $p \geq 0.104$), which coincided with similar postoperative increases in these outcome parameters (e.g., 3–4 kg in abduction strength up to 2- and 5-year follow-up examinations). Compared to the other groups, Boileau type I ASA patients [I(ASA)] had significantly reduced levels of pain (mean 1.6 vs 2.5–3.6 points; $p = 0.002$), increased external rotation at the side (mean 35 vs 9–19°; $p < 0.001$) and increased SPADI (mean 82 vs 57–69 points; $p = 0.008$) and qDASH (mean 21 vs 37–45 points; $p = 0.002$) scores, and Boileau type IV RSA patients [IV(RSA)] had significantly reduced CMS (mean 49 vs 59–66 points; $p = 0.011$) at the 2- and 5-year follow-ups. However, postoperative improvements in CMS, SPADI, and qDASH were similar ($p \geq 0.470$). While almost all of the 32 Group I (ASA) patients reached the lumbosacral junction at 2 ($n = 32$) and 5 years post-surgery ($n = 30$), this proportion ranged from 39 to 88% in the other groups at these later follow-up time points ($p = 0.001$). The sensitivity analysis showed overall consistent results between adjusted and non-adjusted analyses both considering raw (e-Supplement 2) and imputed data. Change in statistical significance between adjusted and non-adjusted analyses was noted for SPADI

($p = 0.005$ and 0.063, respectively) raw data only. In addition, there were significant differences in the CMS between groups despite the similar mean scores, when considering the raw ($p = 0.248$) versus imputed ($p = 0.011$) adjusted data.

At the 24-month follow-up, 13 of 21 Group IV(RSA) patients reported postoperative shoulder improvement and 72 of the 84 patients from the other groups also reported a "much to somewhat better" shoulder status (Table 2; $p = 0.344$). Group IV (RSA) patients, on average, rated significantly lower when asked whether the operation met their expectations ($p = 0.011$). The majority of patients in our four groups reported that they would opt for the same operation again. We observed a similar trend in the levels of both subjective improvement and satisfaction among the groups at 5 years post-surgery (data not shown).

Discussion

With our retrospectively analyzed clinical data, we could describe the course of shoulder pain and function following ASA and RSA for the treatment of proximal humerus fracture sequelae. We wanted to better understand the potential course of clinical improvements and outline possible treatment options for patients with such complex injuries. We found significant improvements in ROM, functional scores, and pain relief following ASA and RSA for all Boileau types up to 2 years post-surgery without any sign of subsequent deterioration by the 5-year follow-up. Patients with Boileau type I sequelae treated with ASA had the greatest improvements of internal and external rotation and higher pain relief compared to patients with RSA and/or other Boileau type fracture sequelae. Patients with Boileau type IV sequelae treated with RSA had the lowest improvements of CMS compared to patients with other Boileau type fracture sequelae. Patient satisfaction was lower in type III and IV RSA patients.

Recent investigations focused on degenerative and not post-traumatic shoulder conditions showed full improvement following ASA and RSA 2 years after surgery [28, 29]. These improvements persisted over 5 years, but flexion declined after 7 years, particularly for patients treated with RSA. While our analysis was restricted to 5 years post-surgery, our data may still help to specifically counsel patients with fracture sequelae regarding their mid-term expectations and tailor postoperative rehabilitation programs.

Recent comparative studies also found higher internal and external rotation capacity in larger populations of ASA versus RSA patients [29, 30]. Boileau and Neyton demonstrated that ASA provided higher external rotation values than RSA in a small number of patients with an intact rotator cuff and type I sequelae [31]. Rotation in RSA depends on the anterior/posterior rotator cuff and

Table 1 Baseline patient demographics and shoulder status of the Boileau fracture sequelae and arthroplasty types

Baseline and operation parameters	Boileau classification of fracture sequelae[a] and arthroplasty type[b]									
	I (ASA)		I (RSA)		II (ASA)	III (RSA)		IV (ASA)	IV (RSA)	
	n (%)	Mean (SD)	n (%)	Mean (SD)	Value[c]	n (%)	Mean (SD)	Value[c]	n (%)	Mean (SD)
Age (years)	32	61 (10)	40	71 (7)	72	14	67 (11)	38	23	66 (11)
Gender										
Female	18 (56)		29 (73)		X	9 (64)		X	14 (61)	
Male	14 (44)		11 (28)			5 (36)			9 (39)	
Am. Soc. Anesth. classification										
I	5 (17)		1 (3)			2 (14)				
II	18 (60)		25 (64)		X	7 (50)		X	13 (57)	
III	7 (23)		13 (33)			5 (36)			10 (43)	
Rotator cuff integrity[d]										
Intact	21 (66)		9 (23)		X	7 (50)		X	5 (22)	
Partial tear	10 (31)		10 (25)			2 (14)			5 (22)	
Full-thickness tear	1 (3)		21 (53)			5 (36)			13 (57)	
Active range of motion (°)										
Flexion	32	85 (29)	40	79 (31)	40	14	57 (28)	0	23	55 (31)
Abduction	32	72 (27)	40	65 (26)	40	14	49 (22)	0	23	43 (22)
External rotation by 0° abduction	32	16 (15)	40	15 (17)	0	14	8 (12)	0	23	7 (12)
Apley's scratch test										
Thumb <LS	17 (53)		28 (70)		X	11 (79)		X	21 (91)	
Thumb ≥LS	15 (47)		12 (30)			3 (21)			2 (9)	
Pain NRS	32	6 (3)	40	5 (2)	4	14	4 (2)	10	23	5 (3)
Muscle strength in abduction (kg)	32	0 (max 7.5)	40	0 (max 8.0)	0	14	0 (max 7.0)	0	23	0 (max 0)
Functional scores										
CMS	31	35 (16)	40	30 (11)	21	14	27 (12)	2	22	23 (11)
SPADI	31	49 (21)	39	36 (17)	22	14	38 (22)	n.a	20	31 (20)
qDASH	32	43 (19)	40	54 (17)	64	14	60 (17)	n.a	20	55 (19)

SD standard deviation, *Am. Soc. Anesth.* American Society of Anesthesiologists Physical Status classification system, *I* a normal healthy patient, *II* a patient with mild systemic disease, *III* a patient with severe systemic disease that is not incapacitating; *LS* lumbosacral joint; pain NRS (Numeric Rating Scale) from 0=no pain to 10=worst pain; CMS (Constant–Murley score) and SPADI (Shoulder Pain and Disability Index) ranging from 0=worst to 100=best; qDASH (quick Disabilities of the Arm Shoulder and Hand) score from 100=worst to 0=best; *n.a.* not applicable

[a]Boileau classification: type I=humeral head collapse or necrosis with minimal tuberosity malunion; type II=locked dislocations or fracture dislocations; type III=nonunion of the surgical neck; type IV=severe malunion of the tuberosities

[b]Type of anatomical prosthesis (i.e., ASA) (*n*)=Promos Standard (15); Lima SMR™ (4); Arthrex Eclipse™ (14); Univers™ II (1) and type of reverse prosthesis (i.e., RSA) (*n*)=Promos Reverse® (51); Lima SMR™ Reverse (12); Univers Revers™ (10); Aequalis® Reversed (4)

[c]Parameter values and categories (X) of single cases

[d]Integrity status of the rotator cuff including the subscapularis, infraspinatus, and supraspinatus tendons
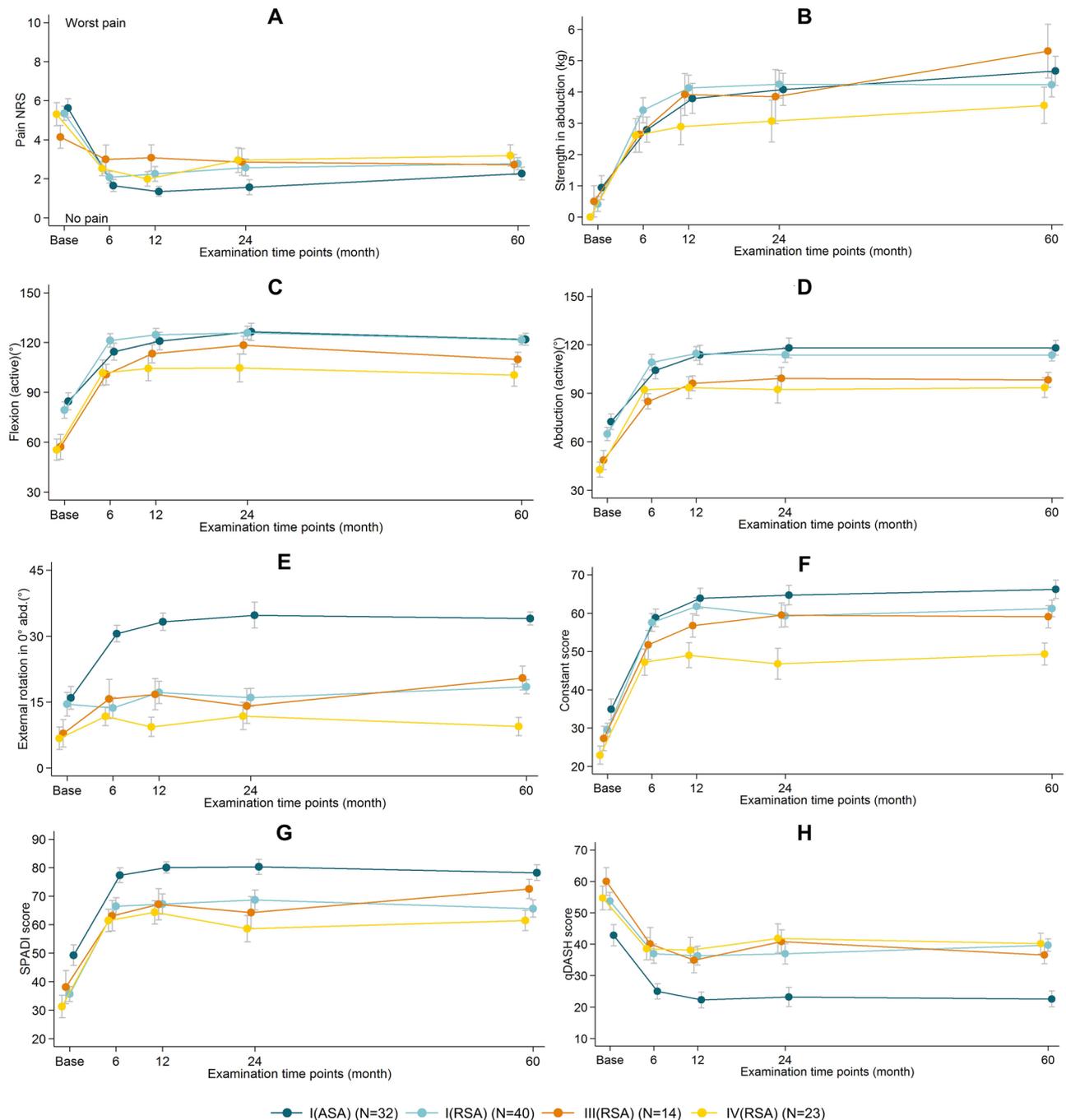
Fig. 2 Baseline and postoperative clinical examination and patient-reported outcome parameters. **a** Pain Numeric Rating Scale (NRS: 0 = no pain to 10 = worst pain); **b** strength in 90° abduction (kg); **c** active flexion (°); **d** active abduction (°); **e** active external rotation in 0° abduction (°); **f** Constant–Murley score (CMS: 0 = worst to 100 = best); **g** Shoulder Pain and Disability Index (SPADI: 0 = worst to 100 = best); **h** Quick Disabilities of Arm, Shoulder and Hand score (qDASH: 0 = best to 100 = worst). *Base* baseline; *I, II, III and IV* Boileau types for proximal humerus fracture sequelae; *ASA* anatomical or *RSA* reverse prosthesis

deltoid, whose functions are decreased in this type of arthroplasty because of alterations in the moment arms, tension, and trajectories [32, 33]. External rotation capacity in RSA patients treated for type I sequelae may not be significantly affected by the preoperative rotator cuff

status [19]. Nevertheless, humeral version, positioning of the glenosphere component, and humeral inclination design are known factors of the rotational capacity in RSA [34, 35], but these factors were not captured in our data. In summary, our results may still suggest that overzealous
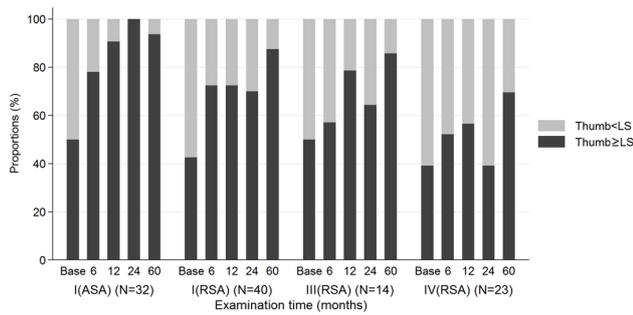
Fig. 3 Achievement of internal rotation using the Apley scratch test for each Boileau type group before and at 6, 12, 24, and 60 months after shoulder arthroplasty. *LS* lumbosacral junction; *Base* baseline; *I, II, III, and IV* Boileau types for proximal humerus fracture sequelae; *ASA* anatomical or *RSA* reverse prosthesis

use of RSA in type I sequelae with intact rotator cuff may sacrifice external rotation capacity.

Our analysis revealed that Boileau types III and IV were associated with decreased external rotation at final follow-up. In these sequelae types, the position of the greater tuberosity is altered by mal- or nonunion. Before the advent of RSA, these conditions consistently required osteotomy of the greater tuberosity [13]. In the case of nonunion, prosthesis instability with superior humeral head migration and impaired shoulder function were observed [36]. Nonetheless, restoration of active external rotation still depends on anatomic positioning of the greater tuberosity [37]. Osteotomy

and anatomic healing of the greater tuberosity [17] may improve external rotation and also prevent dislocation, but may be a difficult task for the surgeon. These observations may also explain the low satisfaction rate which we documented in our patients with types III and IV sequelae.

We observed a significantly higher level of pain relief in patients with type I sequelae treated with ASA compared to those who underwent RSA and were defined with higher types of fracture sequelae. Total shoulder arthroplasty has been found to provide more consistent and effective pain relief against RSA at early follow-up time points [38].

The limitations of our clinical study lie in its retrospective design that inherently introduces selection bias, notably when comparing the groups of type I patients with ASA and RSA. At baseline, patients with type I sequelae treated with ASA were privileged by younger age, less impaired rotator cuff status, better shoulder ROM, and functional scores. In addition, we did not separate patients with a hemiarthroplasty from those with anatomic total shoulder replacement, although the latter may have improved clinical outcomes [12]. Moreover, there were missing values, particularly at the 5-year follow-up, which were managed by multiple imputation. Fourteen percent of our patients were not due for this last follow-up at the time of the analysis, which mitigates the risk of attrition bias due to reasons associated with the outcomes. The size of included patient groups was also limited, which could have introduced a type 2 error. The strength of this study lies in its standardized serial follow-up data,

Table 2 Patient subjective improvement and satisfaction level at 24 months

Patient satisfaction parameters	Boileau classification of fracture sequelae and arthroplasty type[a]				
	I (ASA)	I (RSA)	III (RSA)	IV (RSA)	*P* value
	n (%)	*n* (%)	*n* (%)	*n* (%)	
Status of affected shoulder (n, %)[b]					0.344
Much better	23 (72)	25 (66)	8 (57)	9 (43)	
Somewhat better	4 (13)	8 (21)	4 (29)	4 (19)	
Unchanged	5 (16)	4 (11)	2 (14)	5 (24)	
A little worse		1 (3)		1 (5)	
Much worse				2 (10)	
Rating of expectations met by the operation (n)[c]	31	40	14	21	0.011
Median (range)	9.0 (5.0–10.0)	8.0 (2.0–10.0)	7.5 (3.0–10.0)	7.0 (0–10.0)	
Would decide for the same operation again					0.294
No		1 (3)		1 (5)	
Yes	31 (97)	38 (95)	12 (86)	17 (85)	
I do not know	1 (3)	1 (3)	2 (14)	2 (10)	

P value Kruskal–Wallis test (continuous variables) and Fisher's exact test (categorical variables) *p* values

[a]Boileau classification: type I = humeral head collapse or necrosis with minimal tuberosity malunion; type II = locked dislocations or fracture dislocations; type III = nonunion of the surgical neck; type IV = severe malunion of the tuberosities. Types of prostheses: *ASA* anatomical shoulder arthroplasty, *RSA* reverse shoulder arthroplasty

[b]How are you today compared to before surgery regarding your affected shoulder?

[c]Were your expectations for the operation fulfilled? (Numeric Rating Scale ranging from 0 = not at all to 10 = completely)

which, to date, has not been available in the literature on fracture sequelae. Consistency between sensitivity analyses shows the robustness of our results; we believe that they provide realistic expectations for similar patients treated by shoulder arthroplasty in specialized shoulder clinics.

Conclusion

This study showed that implantation of ASA and RSA provides significant improvements in shoulder pain and function that may remain unchanged between 2 and 5 years after surgery. For patients with Boileau type I sequelae and an intact rotator cuff, surgeons may consider using ASA to maximize external rotation and pain relief.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval Institutional Review Board/Ethics Committee Approval was granted by the Cantonal Ethics Committee of Zurich, Stampfenbachstrasse 121/Postfach, 8090 Zurich, Switzerland. Approval for analyses of the local clinical registry (KEK-ZH Nr. 2014-0483: clinical and subjective long-term outcome after an implantation of a shoulder arthroplasty) was granted on 23.01.2015.

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