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Reverse Total Shoulder Arthroplasty: 14-Year Clinical Experience with 496 Performed Arthroplasties

Reverzní totální náhrada ramenního kloubu: 14 let klinických zkušeností s 496 provedenými artroplastikami

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ABSTRACT

PURPOSE OF THE STUDY

Reverse total shoulder arthroplasty (RSA) can be considered a proven method for the treatment of the most severe shoulder joint affections. In this study, we present 14-year experiences of the authors with the LimaCorporate SMR® RSA system in 496 cases.

MATERIAL AND METHODS

Included in the study are 496 RSAs performed between 2007 and 2020. We successfully followed up 368 shoulders in 358 patients. This was a prospective study with function being evaluated preoperatively and at the last follow-up in 2020. We evaluated the range of motion in active elevation and the classic Constant Score (CS). According to this score, the pain level was also evaluated. Standard statistical methods were used with a paired t-test used for comparisons of values.

RESULTS

The mean follow-up in our group was 5.5 years (0.7–13.6, SD 3.22, median 4.96). Indications were: primary osteoarthritis (84), acute trauma (69), posttraumatic sequelae (79), cuff tear arthropathy (37), RA (29), chronic dislocations (18), final treatment of infectious complications (7), avascular necrosis (6), tumours (4) and TSA revisions (9).

The mean post-operative CS of all patients was 71.9 (2–94, SD 11.26, median 73). The mean post-operative active elevation was 127.35° (30°–180°, SD 28.36, median 130°). The mean pain level at final follow-up was 0.65 (0–3, SD 0.65, median 1). There was a statistically significant improvement In the CS (26.9 to 71) and the final achieved elevation (48.5° to 127.35°) in all groups except acute traumas for obvious reasons. A significant decrease in pain (2.8 to 0.65) was observed in all groups. We saw no implant failures or UHMWPE component wear.

DISCUSSION

We compared our results with those published by other authors. When considering the functional outcomes, our results are comparable with those published previously.

Compared to other studies, an interesting result is the low incidence of scapular notching. In our cohort of patients, it was only present in 10 (2.7%) cases. We attribute this to the design of the SMR® implant which meets the main criterium of a modern shoulder arthroplasty system: modularity of both glenoid components. The glenospheres are available in 36, 40 and 44mm sizes with standard and distalised options. Furthermore, the system also contains the Axioma® revision glenoid component. Humeral stems are available in a range of sizes and lengths including revision stems. The humeral body is also available in two sizes. The short variant is optimal for revision with hemiarthroplasty to reverse conversion.

CONCLUSIONS

During a period of 14 years, we performed 496 implantations of RSAs using the SMR® system. We evaluated 368 cases with an average follow-up of 5.5 years. During long-term follow-up we experienced no implant failures or complications indicative of any constructional insufficiencies. We saw no signs of UHMWPE liner wear. The SMR® system allows for treatment of even the most complex shoulder affections due to its high modularity.

Key words: shoulder joint replacement, reverse shoulder arthroplasty, SMR®, Axioma®, outcomes, ROM, scapular notching, complication, polyethylene wear, UHMWPE.

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INTRODUCTION

Total shoulder arthroplasty (TSA) procedures have a long history, with first attempts already being documented in the first half of the 20th century. These attempts set the trend of further development. Charles Neer is commonly labelled as the father of modern shoulder arthroplasty as he presented 12 patients in 1955 in which he successfully implanted the Vitalia shoulder replacement for proximal humeral fractures (30). Following this study, Neer also reported on the use of his shoulder replacement in patients with osteoarthritis. When objec-

tively evaluating the results, 27 patients reported the outcome as excellent, 15 reported it as satisfactory and 4 patients were very unhappy with the result (32). In the following years, many new studies were published, evaluating the results of the anatomic shoulder replacement (22, 26, 42). Not only Neer, but also other authors highlighted the key importance of an intact rotator cuff for good function of a hemiarthroplasty, as can be seen in studies published between 1974 and 1983 (26, 28, 29, 31). The first attempts to change the implant design in order to not require a fully intact rotator cuff cannot be described as a "reverse" design as we understand it today. We can rather consider them a reverse "constrained" design (10). The first of these implants was the Mark I implant designed by Neer (32). This was followed by the Mark II and Mark III modified variants. Other constrained RSA inventors include Bickel, Lettin and Scales with their „Stanmore" prosthesis (7, 9). Due to the high number of complications of these systems, they were soon removed from clinical practice (7). A new design was presented by Kessel and Bayley in 1979 (23).

Concurrently, "reverse" total shoulder arthroplasty (RSA) implants were being designed that did not utilise a constrained design, but rather the concept of a spherical component fixed to the glenoid and a separate cup as a part of the humeral component. The main differences between these newly developed implants was the method of the glenoid component fixation into the scapula. We can name the Leeds shoulder, constructed by Reeves (1972), followed by implants from Kessel (1973), Kölbel (1973), Bayley-Walker (1973), Fenlin (1975), Buechel (1978) and Gristin and Webb (1978) (10).

A whole new concept, which foreshadowed the new era of the RSA was presented by Paul Grammont in 1985 (13). It was Grammont, who defined several of the crucial features of the new RSA design: The implant must provide stability, the centre of rotation must be distalised and medialised and the centre of the glenoid component „sphere" should be in the glenoid. The first generation of the Grammont shoulder arthroplasty system was associated with numerous complications of the glenoid component. A second generation of the implant was therefore introduced in 1991 with an increased medialisation of the centre of rotation and changes to the glenosphere, changing the size from 2/3 of a sphere to 1/2. The metaglene was fixed not only with a new central press-fit peg, but also with 3.5mm divergent screws (10). In 1994, a third generation of the implant was released which was characterised by changes to the humeral component (6). Following the design philosophy of these implants, the modern Delta Xtend RSA System prosthesis was introduced in 2007 (DePuy Orthopaedics, Warsaw, USA) (2, 3).

Other global manufacturers have continued developing RSA systems in the last 15 years. For example, Zimmer Biomet (Warsaw, USA) initially distributed its Anatomical Shoulder™ Inverse/Reverse System around the world for many years. Due to the increasing importance of the reverse design, especially within the last 5 years, there is a clear growth in the portfolios of various companies. According to their website, Zimmer offers several modifications of the modern arthroplasty system: Comprehensive® Convertible Glenoid System, ASHCOM™ Shoulder, Comprehensive® Reverse Shoulder System, Augmented Baseplate or the Trabecular Metal™ Reverse Shoulder System. Not only large global companies, but also smaller implant manufacturers design RSA systems. This is typical for example on the French market, where a large number of specialised centres along with top shoulder specialists means a range of implants can be found. Examples of these are the *Humerlock Reversed* implant from the FX Solution company (Viriat, France) (16) or the *Arrow shoulder* prosthesis from FH Ortho (15).

An Italian company by the name of Lima LTO S.P.A. created a new TSA system called SMR ® in 2002. The father of this system is prof. Mario Randelli who already began designing a reverse TSA system in 1994. It was a complex, highly modular TSA system which included a reverse variant with the possibility of conversion from hemiarthroplasty to TSA. The SMR abbreviation stands for „*Systema Multiplana Randella"* (34). A subsidiary distribution company of the Italian company Lima LTO S.P.A. (known as LimaCorporate from 2011) was established in 2005 in the Czech Republic. Thanks to this, we began to utilise the SMR® system from 2007 onwards.

The system included both cemented and cementless stems, in 2009 shortened stem variants were introduced and long revision stems were further added in 2013. Considering the glenoid, the 44mm glenosphere was released onto the market in 2009, closely followed by a metaglene with Trabecular Titanium coating. Lastly, a modular component for anchoring the glenosphere in a deficient glenoid (due to bone defects or osteoporosis) was introduced in 2014 – the Axioma® SMR®. Thanks to the SMR® design team optimally combining the work of technologists, constructors and clinical specialists, the system allows for continuity and absolute convertibility between the individual components. Except for stated contraindications, the system is capable of solving practically any affection of the shoulder due to its continuing development.

The LimaCorporate SMR® system has quickly established itself on the Czech and Slovak markets. The main aim of this study is to check the hypothesis of whether the SMR® system shows reliable results in medium- and long-term clinical follow-ups.

MATERIAL AND METHODS

Between March 2007 and August 2020, we performed 496 consecutive implantations of the SMR® RSA system including reimplantations. The vast majority of procedures were performed at our centre – the 1st Department of Orthopaedics, First Faculty of Medicine, Charles University, University Hospital Motol. Some were performed at other departments in the Czech Republic, Slovakia and in other European countries as part of cooperation when starting a reverse shoulder arthroplasty program or as specialised assistance for complicated implantation or revision surgeries.

Indications for performing RSA in our patient cohort:
- osteoarthritis with rotator cuff deficiency,
- rheumatoid arthritis with damage to rotator cuff,
- primary cuff-tear arthropathy,
- necrosis of humeral head with secondary rotator cuff impairment,
- acute proximal humeral fracture,
- post-traumatic sequelae,
- resected proximal humerus,
- revision from hemiarthroplasty to RSA,
- tumours,
- chronic shoulder dislocations, including minor damage to the glenoid.

As **absolute contraindications**, we considered:
- infections in the shoulder region, arthroplasty or osteosynthesis,
- extensive glenoid bone defects without possibility of component fixation,
- complete absence of deltoid muscle function.

Relative contraindications where the risk was assessed on an individual basis:
- patients with a history of alcohol or other drug abuse,
- patients requiring the use of a wheelchair or needing to transfer substantial bodyweight onto crutches,
- noncompliant patients of various causes,
- patients with poorly controlled epilepsy.

The aim of this study was to evaluate our patient cohort at the time of writing – i.e. during 2020.

This method was chosen to review the longevity and reliability of the SMR® RSA system in the longest possible follow-up period.

Fifty patients were deceased (verified from insurance company registries in 2020) and therefore not included in the review. Thirty patients were not available for review, 8 of these were from our department and 22 from other departments where we performed the procedures. Following revision surgery or periprosthetic fracture treatment, 26 cases were continued to be followed-up. The detailed breakdown is in the results section. Overall, 368 implants were reviewed. (Graph 1.)

The study evaluates 368 reverse total shoulder arthroplasties in 358 patients. The procedure was performed bilaterally in 10 patients. There were 110 men with a total of 113 RSAs and 148 women with 255 RSAs. The mean age at the time of surgery was 66 years (range 17.33–85.08, SD 10.43, median 68.06)

The follow-up for each patient consisted of a clinical and radiological evaluation at 3, 6 and 12 months postoperatively. Following this initial interval, patients were followed-up yearly thereafter. In the study, the final follow-up for all patients was performed during 2020.

We prospectively followed all patients, starting with the first RSA procedure that was performed at our centre. In all cases where the diagnosis allowed it (all except acute traumas), we recorded the preoperative function: maximum elevation and the classic Constant score (8). We also recorded the level of pain which was included in the Constant score. The pain was evaluated on a range from 0 to 3 (0 – none, 1 – mild, 2 – moderate, 3 –severe).

When evaluating the results, we used basic statistical methods for all measurements (mean, range, median and standard deviation). To assess the statistical significance of compared values (Constant score, elevation, pain) we used a paired t-test. P values of below 0.01 were considered statistically significant.

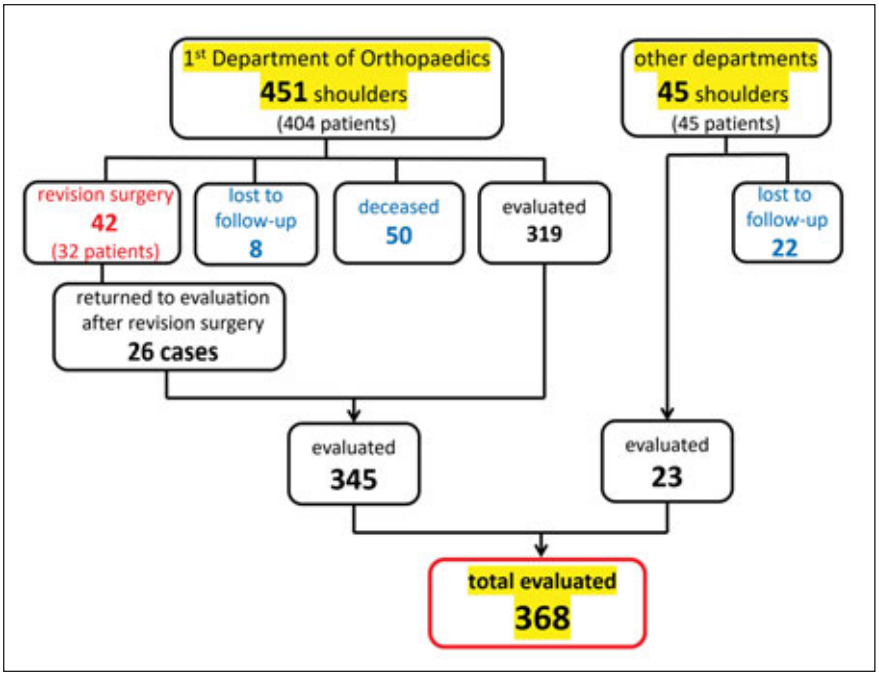
We also performed a detailed analysis of observed complications and revision procedures.

RESULTS

The mean follow-up period was 5.5 years (0.7–13.6 years, SD 3.22, median 4.96).

The number of performed RSAs for individual indications is summarised in Table 1.

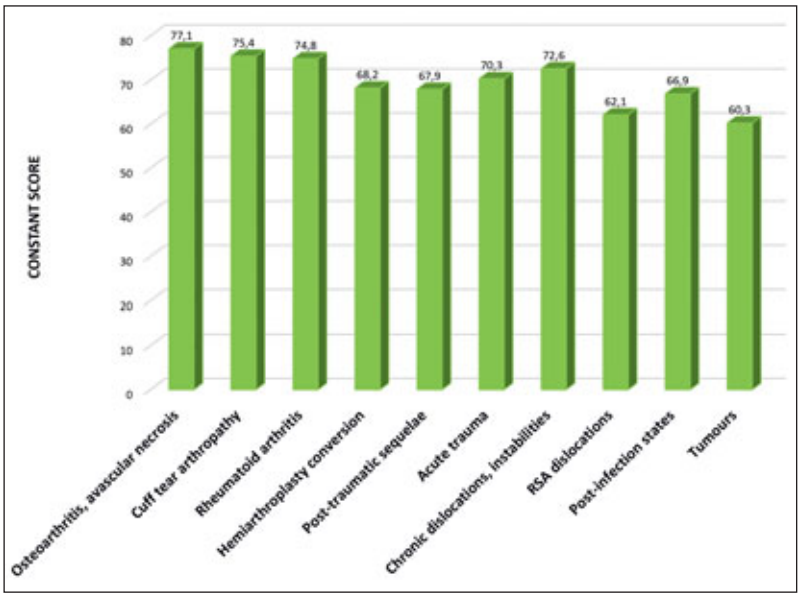
As stated in Graph 1, the evaluation continued in 26 patients where revision surgery was performed and these patients were evaluated in the final year of the study. In 4 cases, the revision was performed for a periprosthetic fracture, in 9 for a dislocation, in 7 cases for a periprosthetic joint infection and in 6 cases for a loosened glenosphere.



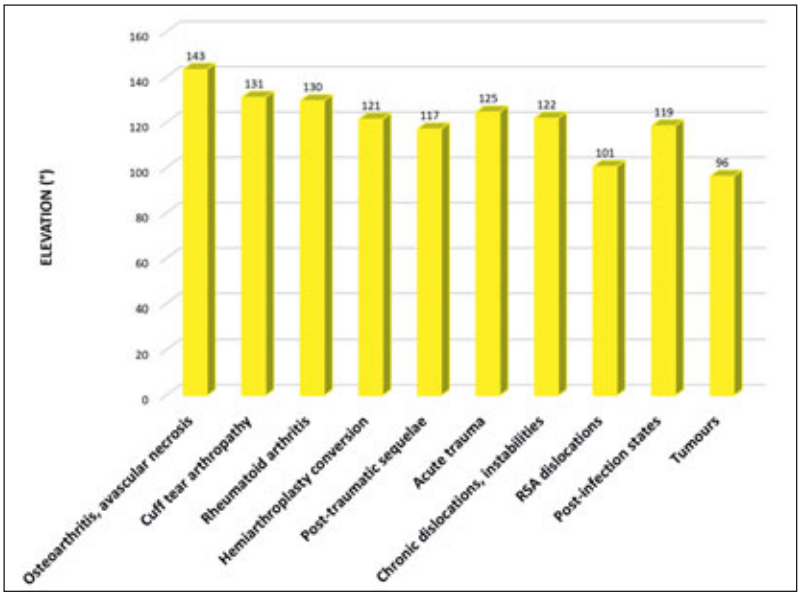
Graph 1. Breakdown of reviewed shoulders in the final assessment in 2020.

Table 1. Indications for performing RSA

Osteoarthritis	84
Post-traumatic sequelae (more than 2 months after injury)	78
Acute trauma (up to 2 months from injury)	69
Cuff tear arthropathy	37
Hemiarthroplasty conversion	27
Rheumatoid arthritis	29
Chronic dislocations. instabilities	18
Post-infection states	7
Avascular necrosis	6
RSA dislocations	9
Tumours	4
Total	368



Graph 2. Resulting mean Constant score in individual indication groups at the time of final evaluation in 2020.



Graph 3. Mean final anterior elevation in individual indication groups at the time of final evaluation in 2020.

For the evaluation of the Constant score and active elevation, patients were divided into groups according to the indications (Graphs 2 and 3). Graphs 4 and 5 show the difference in Constant scores pre-operatively and at final evaluation in the individual groups. The detailed values are given in Table 2. Results of pain evaluation are shown in Table 3 and Graph 6.

Complications

Overview of observed complications and their treatments is provided in Table 4.

A statistically significant ($p < 0.01$) improvement in Constant score, forward elevation and a decrease in post-operative pain was observed in all indication groups except tumours. In the tumours group where only 4 shoulders were evaluated, we found a statistically significant improvement in Constant score ($p = 0.006$) but the improvement in pain was above the level of statistical significance ($p = 0.015$). When we evaluated the change in forward flexion ($p = 0.703$) in the tumours group, we found a worsening of the range of movement post-operatively which is certainly due to the radical resection of soft tissues around the tumour.

DISCUSSION

As we have stated in the introduction, the aim of our study was to assess our patient group in the longest follow-up possible. We wanted to ascertain the longevity of the RSA and to evaluate possible complications.

We excluded patients that died before 2020 from our study. Nevertheless, as stated in the materials and methods section, these patients were also followed up after RSA implantation according to our standard regimen. When we examined the patient records, these patients had no implant complications.

We compared our results to assessments published by other authors. A limiting factor in this comparison is the use of various outcome measures between different studies.

Ball et al. published their five-year minimum results of using the DePuy Delta Xtend RSA (DePuy Orthopaedics, Warsaw, USA) system in 2020. They evaluated 93 patients where that specific implant was used between June 2007 and June 2012. When evaluating the functional results, they completely evaluated 57 patients out of the original 93. These were followed for an average of 81 months (6.7 years) with a range of 5–9.5 years (2). The function of the operated joint was assessed by the possible range of motion in forward

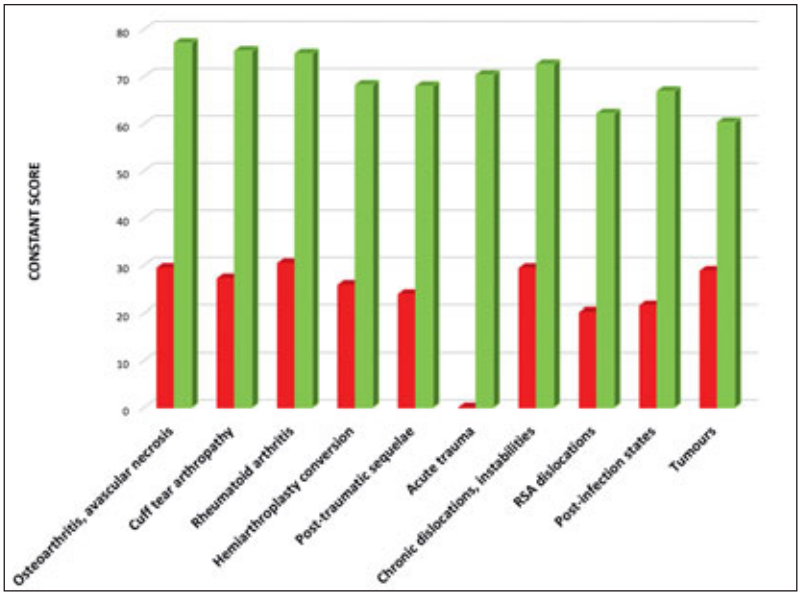
Table 2. Numerical overview of the results (CS- Constant score. SD – standard deviation. TSA – total shoulder arthroplasty)

		Osteo-arthritis. avascular necrosis	Cuff tear arthro-pathy	Rheu-matoid arthritis	Hemiar-throplasty conver-sion	Post-traumatic sequelae	Acute trauma	Chronic dislo-cations. instabilities	RSA disloca-tions	Post-in-fection states	Tumours
	Evaluated (TSA)	90	37	29	27	78	69	18	9	7	4
Before surgery	**CS average**	**29.39**	**27.16**	**30.38**	**25.78**	**23.81**	**–**	**29.33**	**20.11**	**21.43**	**28.75**
	CS minimum	20	19	20	13	10	–	12	8	12	25
	CS maximum	39	35	37	37	36	–	48	29	34	33
	CS median	30	27	30	25	25	–	29.5	20	20	28.5
	CS SD	2.88	3.27	3.88	4.99	4.63	–	8.21	5.65	6.90	2.92
	Elevation average	**65.39**	**35.14**	**56.55**	**44.63**	**33.72**	**–**	**54.72**	**23.89**	**38.57**	**98.75**
	Elevation minimum	30	15	30	25	10	–	10	10	15	70
	Elevation maximum	90	65	100	60	60	–	90	45	75	140
	Elevation median	65	35	50	45	35	–	60	20	40	92.5
	Elevation SD	9.70	10.69	14.45	8.92	9.95	–	19.82	9.65	18.46	26.07
After surgery	**CS average**	**77.07**	**75.41**	**74.83**	**68.19**	**67.91**	**70.30**	**72.56**	**62.11**	**66.86**	**60.25**
	CS minimum	45	53	29	35	35	38	30	34	38	51
	CS maximum	94	90	90	94	90	88	90	85	84	75
	CS median	78	77	76	67	68	72	74	64	69	57.5
	CS SD	7.88	7.79	10.92	14.30	11.81	9.79	12.32	13.44	12.98	9.09
	Elevation average	**143.44**	**131.08**	**129.66**	**121.48**	**117.18**	**124.64**	**121.94**	**100.56**	**118.57**	**96.25**
	Elevation minimum	75	60	40	40	40	45	30	30	40	70
	Elevation maximum	180	175	170	170	170	170	175	155	160	130
	Elevation median	145	140	130	125	120	125	125	110	125	92.5
	Elevation SD	19.24	27.85	25.39	31.03	29.5	24.04	28.44	35.39	35.23	22.19

flexion where there was an average of 142°. The ASES (American Shoulder and Elbow Assessment Score) improved on average from 27.6 to 78.5. More detailed results were not published.

What we found interesting in this study are their conclusions regarding implant design and operative technique. Bell et al. highlight the importance of implanting the metaglene as inferiorly as possible into the glenoid surface. This ensures optimal placement of the glenosphere with slight inferior overhang which they state is key for prevention of scapular notching by the humeral component impacting against the scapula (2). To back up this argument, they refer to the biomechanical study by Nyffeler et al. (33). Furthermore, Ball et al. state that at as a part of the system modularity, they prefer to use a larger glenosphere – 42mm with a distalisation of the centre of rotation. (2, 33). Their preferences are completely in line with our experiences and beliefs.

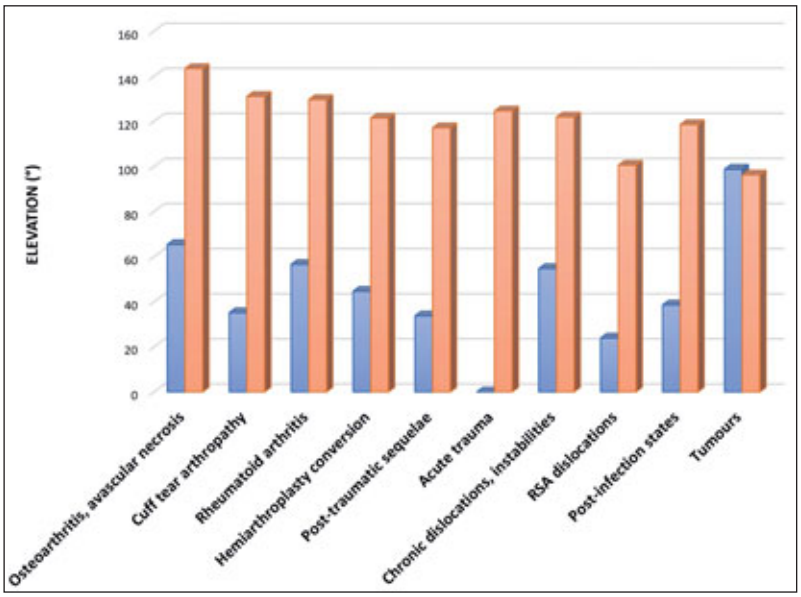
Another study which we found interesting was one by **Chou et al.** In their study, they simulated the biomechanical situation of an implanted reverse SMR® LimaCorporate prosthesis. More specifically, they examined the differences between different glenosphere designs: 36mm concentric, 36mm eccentric, 44mm concentric and 44mm eccentric. If we summarise their findings, they clearly proved that the 44mm eccentric



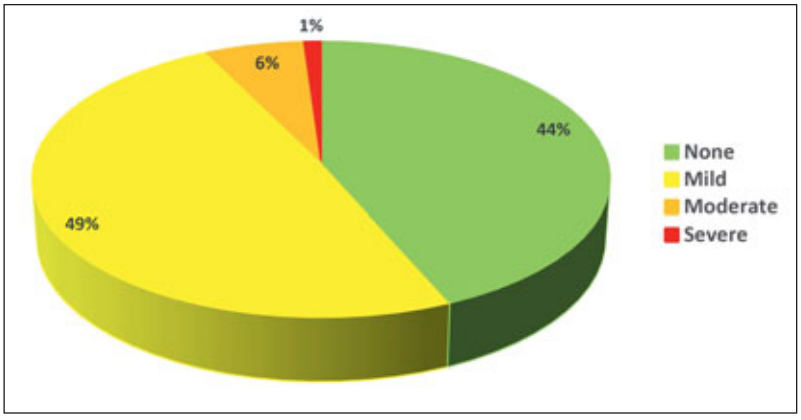
Graph 4. Comparison of preoperative function (Constant score) preoperatively (red) and at final evaluation in 2020 (green) in individual groups.

Table 3. Recorded pain levels before and after surgery at time of final evaluation.

Pain by Constant score (0-none, 1-mild, 2-moderate, 3-severe)								
Indication	**Before surgery**		**After surgery**		Number of patients (after surgery)			
	Average	Median	**Average**	Median	None	Mild	Moderate	Severe
Osteoarthritis	**2.77**	3	**0.51**	0	47	40	3	0
Cuff tear arthropathy	**2.62**	3	**0.51**	0	20	15	2	0
Rheumatoid arthritis	**2.76**	3	**0.41**	0	20	7	1	1
Hemiarthroplasty to RSA revision	**2.78**	3	**0.74**	1	12	11	3	1
Posttraumatic sequellae	**2.92**	3	**0.90**	1	15	57	5	1
Acute fracture	**2.93**	3	**0.68**	1	28	35	6	0
Instability, chronic dislocation	**2.83**	3	**0.61**	1	8	9	1	0
Revision for RSA dislocation	**2.78**	3	**0.44**	0	6	2	1	0
Post-infection states	**2.29**	2	**0.86**	1	3	3	0	1
Tumours	**2.25**	2.5	**1.00**	1	1	2	1	0
Total	**2.80**	3	**0.65**	1	160	181	23	4



Graph 5. Comparison of preoperative anterior elevation (blue) and at final evaluation (red) in individual groups.



Graph 6. Graphic visualisation of the pain level in all patients at the final follow-up in 2020 (0–3 points according to Constant score).

glenosphere increases the average range of motion for both adduction (by 17.7°) and abduction (by 29°). Adduction is linked to the distalisation of the centre of rotation: an eccentric 36mm glenosphere is distalised by 4mm and the eccentric 44mm glenosphere by 2mm. The concurrent distalisation and increase in possible adduction are key factors for the prevention of scapular notching. We have clearly observed this when performing the radiographic evaluation of our patient cohort (18).

The **scapular notching phenomenon** has been widely discussed in previously published studies (36, 38). Ball et al. (2) observed scapular notching in 69% of cases after implantation of the DePuy Delta Xtend prosthesis. Of those, 20% were grade III and IV according to the classic grading system (39). In correlation with other published studies, Ball et al. also state that this phenomenon rarely causes subjective problems to the patient but long-term complications in 10 or more years cannot be predicted. This differs from our observation of this phenomenon. In our patient cohort, we observed only 10 cases of scapular notching in all of the 368 evaluated shoulders. Grade II notching occurred in 9 cases with the remaining case being a grade III/IV. None of the patients stated any subjective problems. We attribute the low rate of scapular notching primarily to the design of the SMR® shoulder system but also due to our early utilisation of the 44mm glenosphere after its introduction in 2009. The

Table 4. An overview of recorded complications and their treatments

COMPLICATIONS		
No. of complications treated operatively	42	In 32 patients
Dislocations		
Total dislocations	28	In 17 patients
No. of dislocations up to 3 months post-surgery	20	
	Dislocation before 1 month post-surgery	9
	Dislocation between 1–2 months post-surgery	9
	Dislocation between 2–3 months post-surgery	2
No. of dislocations after 3 months post-surgery	8	
No. of dislocations treated conservatively	5	Closed reduction in GA + Dessault
No. of dislocations treated operatively	23	
	Open reduction (without component exchange)	7
	Glenoid component reimplantation	1
	Humeral component reimplantation	5
	Exchange for a thicker liner	10
PERIPROSTHETIC FRACTURE		
Periprosthetic fracture	6	4x operative
INFECTION		
Infection	8	8x operative
	Revision. pulsed lavage. exchange of bearing surfaces	4
	Extraction. spacer. two-stage reimplantation	4
Other		
UHMWPE component wear	0	
Radiographic signs of osteolysis as a consequence of UHMWPE wear	0	
Scapular notching	10	0x operative
Glenosphere loosening	6	6x operative
Humeral component loosening	0	0x operative
Late deltoid muscle atrophy	4	0x operative
Acromion stress fracture	2	1x operative
Intra-operative complications	1	Post-traumatic brachial artery injury

44mm glenosphere provides distalisation of the centre of rotation. The 44mm glenosphere size was used in the majority of our shoulders (90%).

Two main factors affecting the development of scapular notching:

1) Implant design: glenosphere diameter, metaglene component design with the possibility of glenosphere distalisation and inclination of humeral articulating surface (the neck-shaft angle).

2) Placement of the metaglene so that it copies the inferior border of glenoid as closely as possible.

These factors are clearly supported by various studies. Young et al. for example described a 24% incidence of scapular notching when using the SMR® system, all of which were of a lesser grade (46). Conversely, multiple studies of the Delta III system reported an incidence of 44% to 96% (39, 44, 45).

From our experience, another important feature when selecting a shoulder arthroplasty system is **the possibility of conversion from hemiarthroplasty to reverse total arthroplasty**. Furthermore, we also consider it very important that there is the **possibility to perform a reverse shoulder revision with conversion to a hemiarthroplasty with a specially designed head component**. This specialised humeral head component is the last possibility in the treatment of reverse shoulder arthroplasty failure. The shape of this head is identical to the anatomic replacement but has an extended surface to fit in the coracoacromial arch, thereby preventing contact between the remaining metaphyseal bone (greater tubercle region) and the acromion. In the SMR® system, this component is called the CTA (cuff tear arthropathy) head.

When we examine the shoulder arthroplasty portfolios of several manufacturers, the convertibility which

we have mentioned is often absent. This is due to the completely differing designs of their anatomical and reverse shoulder arthroplasty systems.

While other manufacturers state in their surgical manuals that the conversion is possible, when we study them in detail, we find that in reality it can be quite problematic. In our experience, it is quite often necessary to use a shortened variant of the proximal humeral body when converting an anatomical variant to the reverse, while retaining the anchoring stem in the humeral shaft. If the system does not allow for this possibility, an extraction of the entire humeral stem is necessary. Needless to say, this is often very difficult or even impossible without significant damage to the ingrown bone.

Another problematic area in reverse shoulder designs is **the method of primary fixation of the glenoid component**. Some systems use smooth and thin cortical screws for this purpose. In our experience, these screws often failed to provide sufficient stability in the shallow glenoidal bone due to stripping of the surrounding bone during screw insertion. Later, the possibility of fixation using angular stable-locked screws was introduced. This was supposed to provide higher primary implant stability. Harman et al. examined this problem in detail. They compared different fixation possibilities of two baseplate designs in the Delta III (DePuy Orthopaedics, USA) and Reverse Shoulder Prosthesis (RSA) (Encore Medical Corp, USA) systems. The conclusions of this biomechanical study showed that the strength of the primary metaglene fixation depends on both the screw diameter (comparison of 3.5 and 5.0 mm diameters with 5.0 showing better fixation) and the angular locking of the screws (angular stable-locked screws provided better fixation). The glenosphere design however seemed to have the predominant effect on primary stability. With the same glenosphere diameter, the Delta III glenosphere has a 16mm lateral offset while the RSA has two variants with either 23 or 27mm lateral offsets. In geometrical terms, we can define the glenosphere as a sphere that has a set diameter but can have a varied height of the spherical cap. This height defines the amount of lateralisation. It is the amount of lateralisation of the glenosphere spherical centre which directly determines the shear forces acting on the bone-prosthesis interface (14). We consider the use of angular stable-locked screws in RSA controversial. The high rigidity of the metaglene and screw interface can lead to breakage of the screws or their dissociation along with part of the scapular bone. These complications are documented in multiple studies (11, 25, 35, 37, 40, 41).

In their study from 2017, **Beltrame et al.** evaluated 33 operated cases of cuff-tear arthropathy using the SMR® system (4). Their study also highlights the importance of the growing range of components in the system, including the eccentric 44mm glenosphere which favours the biomechanics of the reverse shoulder arthroplasty by increasing the possible adduction without allowing for contact between the humeral component and the glenoid, thus preventing the development of scapular notching. Their average follow-up was 26 months (18–65 months). The range of motion was recorded continuously with the maximum range of motion obtained at 1 year after implantation (which also according to our experience can be considered as the time when the function of the operated shoulder stabilizes). The achieved active anterior elevation was on average 150° (140°-170°). Correlating with other published studies, recorded exorotation did not show any improvement and remains problematic. Beltrame et al. reported the mean active exorotation as 25° (range of 10°–30°) (4).

Young et al. published an evaluation of 56 SMR® reverse shoulder arthroplasties, implanted between 2004 and 2006 (46). The most common indications were cuff tear arthropathy and osteoarthritis with rotator cuff deficiency which together made up 66% of cases. In 16% of cases the indications were fractures or fracture sequelae. In one case the arthroplasty was performed as treatment for chronic shoulder dislocation. The authors state that they have used the Delta III prosthesis (DePuy, Warsaw, USA) from 1999 but due to early concerns regarding glenoid fixation, they began using the SMR® system instead since 2003. In their study they cite a number of publications evaluating the Delta III implant. Valenti et al. (43) for example, reported on the need for revision surgery in 15% of patients, while Werner et al. reported a 33% revision rate after 3 years (45). In most cases, the reason for revision was a loosened glenosphere. In their study, Young et al. voice their opinion that the use of 6.5mm cancellous screws in the glenoid is superior. As they state, the surgeon can decide to insert the screws in the direction that they feel contains the strongest bone, thus ensuring perfect primary fixation of the implant (46). This opinion correlates perfectly with our experiences. Patients in the study by Young et al. had a mean 38-month follow-up (24–66 months range). 92% of patients reported no pain and 89% rated their outcome as good or excellent. The mean active anterior elevation was 122° (45°–180°), the mean external rotation ranged from 25° to 75° (46).

Concerning clinical results, the best reported results of achieved range of motion was in the cuff tear arthropathy, osteoarthritis with or without rotator cuff insufficiency and rheumatoid arthritis with early stage joint destruction indication groups. These results correlate with many published studies (1, 2). There is a generally reported trend of worse outcomes when treating acute traumas or trauma sequelae when compared to degenerative conditions (21). When we evaluated our patients, we found a significant difference in the range of functional results between these groups. When we however compared the average achieved results, the differences were not so significant.

When evaluating **reverse TSA dislocations**, it is necessary to differentiate between early and late dislocations. Early dislocations are usually caused either by a surgical error or more commonly due to a gross failure in the postoperative care regime. If the dislocation occurs after more than six months post-surgery, it is usually due to a clear traumatic event. The reported rate of

dislocations varies in published studies – ranging from approximately 10% up to 30% (5, 12, 47).

Reported occurrence of other complications is similarly varied. Ball et al. for example did not observe any **infections** in their patients (2). In our cohort, we observed 7 cases of periprosthetic joint infections. In one case, the infection was purely superficial and localised in the proximal part of the wound. In all cases, one of the following risk factors was present:
– previous surgical procedure on the shoulder joint (fracture fixation, repeated stabilisation surgeries for chronic instability etc.),
– immunosuppressant or biopharmaceutical therapy,
– previous infection in the shoulder region.

According to published studies, the incidence of periprosthetic joint infection ranges from 1 to 10% 19, 20, 27).

We observed **glenosphere loosening** in 6 cases. In three cases, this was a direct result of a fall. In all cases, this complication was treated by a removal of the loosened component and implantation of a new one. In the other three cases, there was a loosening of the metaglene which was not visible on radiographs. None of these patients reported any traumatic events. Revision surgery was performed for shoulder pain of unknown aetiology. During the revision surgery, a slight failure of metaglene osseointegration was found in these patients.

A highly discussed phenomenon is the late **atrophy of the deltoid muscle.** The exact cause is unclear. In some cases, the changes in the muscle tissue are attributed to excessive prolongation of the arm after implantation of RSA. In the 4 patients that had this complication in our study, all had a history of severe degenerative conditions of the cervical spine. Three of these patients underwent spinal surgery before implantation of the RSA. In all patients, chronic neurologic changes on the affected limb were observed.

The occurrence of **heterotopic ossifications** differs between published studies (24). In our patients, we observed the presence of slight ossifications that did not affect the functional result in 12 patients operated for acute trauma. One patient developed large ossifications very early after the surgery. An infectious cause was excluded, and the real cause remains unknown.

It can be stated that (mentioning only the most important parameters) a **modern reverse total shoulder arthroplasty system** should meet the following criteria:

Glenoid component

- For a standard primary arthroplasty, the system must contain various metaglene sizes, with pegs of various sizes and diameters. The ingrowth surface must be treated with modern methods for enabling osseointegration.
- For more complicated cases, bony defects, severe osteoporosis or revision surgeries, the system must contain a different variant. The requirement should be for the glenoid prosthesis – the metaglene – to be made up of separate baseplate and peg components. Both components should be available in a range of sizes. The ingrowth surface allowing osseointegration should utilise porous 3D coating technology – for example the Trabecular Titanium (TT®) or Trabecular Metal (TM®) technologies. These separate components allow for selection of individual baseplate and peg sizes according to the surgical finding, followed by their final assembly and implantation.
- The glenosphere component should allow for sufficient distalisation of the centre of rotation so that its distal edge is at the same height or overlapping the distal edge of the glenoid even with a standard implantation of the glenoid component. This can be achieved for example by the eccentricity of the glenosphere against the metaglene. Glenospheres must also be available in 40 and 44mm sizes, the possibility of lateralisation with a modular offset conus is advantageous.

Humeral component

- The distal construct is made up of the stem onto which a reverse humeral body is attached. It should be possible to easily disassemble the components even after implantation. Various humeral body variants should be compatible with an implanted stem including the anatomical body which in turn should allow the pairing with either an anatomical head or a special head in case of cuff tear arthropathy (CTA®).
- The reverse humeral body should be available in a both standard and shortened variants. The shortened component is especially necessary during hemiarthroplasty to reverse revision (when the stem is left in the humeral shaft). When performing a conversion with any shoulder system, it is necessary to keep in mind the humeral reverse body will need to be shorter than the anatomical body.
- Cementless variants are always preferred (if the bony substrate allows for it). The basic stem construction should include fins to provide rotational stability and a rough surface along with the shape ensuring longitudinal stability in non-cemented implants.
- Cemented variants – for non-standard situations – should have a polished surface with longitudinal grooves for rotational stability.
- System must contain a large range of stem sizes: standard, thin, shortened or long revision.

Based on our own experiences, we do not recommend the use of cemented stems unless necessitated by specific factors during the surgery. From our experience of the many times we have been forced to perform a revision procedure (including patients from other departments) with the need to change one of the components, the removal of the cemented stem was extremely difficult, with the cement bed itself often being impossible to remove. When cementless stems from the SMR® system are used, both primary fixation and secondary integration are guaranteed.

We have been able to verify the perfect primary fixation of the stem in the diaphyseal cortical bone in cases where the proximal humeral substrate is insufficient or completely absent. In these cases, the humeral body has

no contact with the metaphyseal bone and the stem is the only part providing primary stability. The double fin design of the stem provides perfect fixation, provided the size is selected correctly. These situations arise most commonly in patients with acute trauma or posttraumatic sequelae.

CONCLUSIONS

Reverse total shoulder arthroplasty can be considered a proven method of treating the most severe affections of the shoulder joint.

In comparison to hemiarthroplasty, there is no requirement for intact rotator cuff function. Conversely, preservation of the physiological function of the deltoid muscle is essential.

In this study, we present 14 years of clinical experience in 496 cases of reverse total shoulder arthroplasty. We evaluated 368 shoulders in 358 patients with a mean follow-up period of 5.5 years. We had no implant failures in our cohort. In all indication groups (except acute traumas for obvious reasons), there was a statistically significant improvement in the recorded Constant score. We also proved a statistically significant improvement of range of motion in all indication groups except the tumours group.

Thanks to the high modularity of its components, the SMR® system allows for the treatment of even the most complicated shoulder affections. The baseplate and peg are provided in various sizes, including the new Axioma® system, allowing for absolutely stable primary fixation even in defective or osteoporotic glenoid bone stock. The bearing surfaces allow for choice between 36, 40 and 44mm diameter glenospheres in both standard and eccentric variants. The humeral component is comprised of the reverse humeral body and the stem. A large variation of stem sizes and lengths is available, including variants for revision surgery. The humeral body is also available in two variants, where the short reverse humeral body is optimal for conversion from hemiarthroplasty to reverse total arthroplasty.

Our study confirmed the hypothesis that the SMR® system provides good clinical results. We saw no implant failures or complications that would infer a construction deficiency limiting its longevity.

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