Current Concepts Review

Short- to medium-term outcomes and future direction of reverse shoulder arthroplasty: Current concepts

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ABSTRACT

Reverse shoulder arthroplasty is typically indicated for patients with severe shoulder osteoarthritis, rotator cuff tear arthropathy, or proximal humerus fractures that have failed to heal properly. The primary goal of reverse shoulder arthroplasty is to improve shoulder function and reduce pain, while also restoring the ability to perform daily activities.

There is a growing body of evidence supporting the effectiveness of reverse shoulder arthroplasty in improving shoulder function and reducing pain in patients with severe shoulder osteoarthritis or rotator cuff tear arthropathy. Reverse shoulder arthroplasty is associated with significant improvements in shoulder function and pain reduction compared to non-surgical treatments.

This paper aims to summarize current knowledge, practices and present a summary of the long-term effects of reverse shoulder arthroplasty (RSA) on patient outcomes, including how these outcomes are defined and what measures are typically used to assess them. It will also cover newer definitions of outcomes for RSA that have been developed in recent years in order to better understand the long-term effects of the procedure on patient-reported outcomes and functional ability, as well as information on revision surgery and implant survivorship, and the future of RSA (3D-navigation, patient-specific instrumentation, robotics and artificial intelligence) and its effects on outcomes.

Current Concepts

- Reverse shoulder arthroplasty (RSA) was designed based on two biomechanical principles: lowering the humerus and medializing centre of rotation at the glenoid component. This design has the benefit of increasing the strength of the deltoid muscle through tensioning and reducing mechanical torque at the glenoid component, which can prevent loosening.
- Indications for RSA have expanded over time as even patients with pre-operative deltoid impairment or rheumatoid arthritis have shown considerably good outcomes.
- RSA leads to improvement in shoulder mobility and patient-reported outcomes. The more recent methods of individual success of a patient's RSA surgery include attainment of minimal clinically important difference (MCID) and substantial clinical benefit (SCB). Patient-reported outcome measures and patient satisfaction rates are high even after long-term follow-up, with the majority of patients experiencing improvement in pain scores and better function. Revision rates are high in the long term and more longer-term studies are needed to validate the long-term efficacy of RSA.
- There is a paucity of literature regarding the effect of using 3D preoperative planning software, patient-specific instrumentation, robotics and artificial intelligence for component placement, on long-term outcomes. Further studies are needed to evaluate the efficacy of these novel methods in maintaining long-term outcomes.
Future Perspectives

- There has been significant progress in the use of innovative technologies for Reverse Shoulder Arthroplasty (RSA), such as 3D preoperative planning software and patient-specific instrumentation, which have shown improvement in surgical precision compared to standard 2D imaging.
- Computer navigation during RSA implantation is emerging as a promising approach, demonstrating less surgical time compared to non-navigated methods, similar improvements in range of motion and functional outcome scores, and a trend towards lower rates of complications.
- Advancements beyond traditional RSA include the use of artificial intelligence and robotics. Examples include an automated deep learning algorithm that could identify implants with high accuracy, and a robotic platform for rapid creation of a mould of the glenoid joint surface to improve accuracy. Despite their potential, challenges in safety, efficacy, surgeon training, and regulatory and ethical issues still need to be addressed.

1. Introduction

Reverse shoulder arthroplasty is indicated for patients with severe shoulder osteoarthritis, rotator cuff tear arthropathy, or proximal humerus fractures that have failed to heal. This paper aims to summarize current knowledge, practices and present a summary of the long-term effects of reverse shoulder arthroplasty (RSA) on patient outcomes, including how these outcomes are defined and what measures are typically used to assess them. It will also cover newer definitions of outcomes for RSA that have been developed in recent years in order to better understand the long-term effects of the procedure on patient-reported outcomes and functional ability, as well as information on revision surgery and implant survivorship, and the future of RSA (3D-navigation, patient-specific instrumentation, robotics and artificial intelligence) and its effects on outcomes.

The semi-constrained reverse shoulder prosthesis was designed based on two biomechanical principles: lowering the humerus and moving the centre of rotation at the glenoid component towards the midline. This design has the benefit of increasing the tension of the deltoid muscle and reducing mechanical torque at the glenoid component, which can prevent loosening [1]. The current Delta III reverse prosthesis was launched in 1991 [2], with FDA approval for it being granted in 2003 [3]. The number of high-quality, long-term studies on their outcomes however is limited. The incidence of reverse shoulder arthroplasty in the United States by 2025 is expected to be about 300,000 [4], and is projected to rise significantly, with a 122 % increase by 2040 [5] and 333 % increase from 2011 to 2030 [6].

2. Definitions of study duration

In existing literature, the definitions of what constitutes “short-term,” “mid-term,” and “long-term” outcomes vary widely, and there is no clear consensus. The inconsistency in the definition of study duration can make it difficult to compare the results of different studies and to draw conclusions about the long-term effects of RSA. As a general rule, the follow-up duration for short-term, mid-term and long-term studies on RSA can be defined as 2 years, 5 years and 10 years, respectively.

3. Evaluating the efficacy of reverse shoulder arthroplasty based on different forms of outcomes

3.1. Improvement in mobility

One major advantage of reverse shoulder arthroplasty (RSA) is the improvement in range of motion (ROM) after the surgery [7–10]. Overall, reverse shoulder arthroplasty (RSA) has been found to lead to greater improvements in range of motion, in patients with cuff tear arthropathy compared to revision of anatomic prostheses, failed rotator cuff repair and fracture sequelae [11]. In multiple studies with short and medium-term follow-ups, most patients demonstrated significant improvement in range of motion (Table 1).

Other options for shoulder arthroplasty include the anatomic total shoulder arthroplasty (TSA) and hemiarthroplasty. While literature seems to suggest that anatomic TSA showed the best ROM improvement (particularly external rotation) in comparison to RSA and hemiarthroplasty [14–17], the choice of implant should be tailored to each patient’s specific condition and needs. In cases where there is an intact rotator cuff tendon, anatomical TSA may be considered instead.

In Nunes [7] et al.’s systematic review comprising about 1700 patients, active range of motion (ROM) improved for forward flexion (mean change 47°–82°), abduction (mean change 43°–80°), external rotation (mean change 8°–39°) and internal rotation (mean change −2 to 1 points). Specific to forward flexion, Wall et al [10] found that the mean forward flexion improved from 86° to 137° at a mean follow-up of 29.9 months of 240 prostheses in 232 patients. Stechel et al. [18] found that forward flexion improved from 47° to 105°. Bacle et al. [19] found in their study of 87 prostheses in 84 patients with a mean follow-up of 150 months that forward flexion improved from 81° to 131°. While significant improvements in forward flexion are noted, a time-dependent reduction in ROM, is also commonly noted past medium-term follow-up [19,20]. The gradual reduction in ROM may be due to attrition of the deltoid. Favard et al. [20] noted a time-dependent reduction in ROM in their group of patients from 5 to 9 years postoperatively. The lowered and medialized centre of rotation in RSA caused the deltoid to undergo a non-physiological contraction-stretching cycle, which may hinder the muscle’s ability to adapt to repetitive movements and decrease its motor performance over time [2,19]. Therefore, patients could expect a significant improvement in ROM (forward flexion) even 10 years after RSA; however, this will tend to decrease over time.

Interestingly, in contrast to forward flexion, the long-term improvement in external rotation was not observed. A systematic review by Ernstbrunner et al. [12] which comprised 8 studies with a total of 365 shoulders showed active external rotation remained unchanged post-RSA. Stechel et al. [18] and Favard et al. [20] reported an increase in active external

Table 1

<table>
<thead>
<tr>
<th>Nature of Study</th>
<th>Author</th>
<th>Year</th>
<th>Journal</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Review/Meta-Analysis</td>
<td>Nunes et al. [7]</td>
<td>2021</td>
<td>CORR</td>
<td>9 studies, 1670 patients, mean follow-up 41.1 ± 5.6 months, improved active forward flexion (mean change 47°–82°), abduction (mean change 43°–80°), external rotation (mean change 8°–39°).</td>
</tr>
<tr>
<td>Systematic Review/Meta-Analysis</td>
<td>Ernstbrunner et al. [12]</td>
<td>2019</td>
<td>JSES</td>
<td>8 studies, 365 shoulders, mean follow-up 9.5 years, Active anterior elevation and abduction improved significantly (p = 0.004 and p = 0.009) respectively. No significant change in active external rotation.</td>
</tr>
<tr>
<td>Systematic Review/Meta-Analysis</td>
<td>Bois et al. [13]</td>
<td>2020</td>
<td>JSES Int</td>
<td>43 studies comprising 1041 RSAs, mean follow-up period of 43.8 months. Range of motion improved in all groups, except for external rotation</td>
</tr>
</tbody>
</table>
rotation at short- and medium-term follow-up, but this was not maintained at long-term follow-up. A potentially significant factor for this is the condition of the teres minor, which aids external rotation. In a study by Simovitch et al. patients with stage 0–2 fatty infiltration who underwent RSA demonstrated superior Constant scores and greater preoperative-to-postoperative improvement compared to those with stage 3–4 infiltration of the teres minor [21].

3.2. Traditional patient-reported outcomes

Outcomes of reverse shoulder arthroplasty (RSA) have traditionally been defined based on the success or failure of the surgery. However, more recently, patient-reported outcome measures (PROMs) have become more commonly used to evaluate the effectiveness of RSA. PROMs allow patients to make informed decisions about their care based on evidence-based information and provide quality assurance about their surgery. Some common PROMs that are used in the evaluation of RSA include the Constant-Murley score [22], the Simple Shoulder Test [23], and the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire [24] and American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form [25]. A systematic review by Bois et al. [13] comprising 43 studies (1041 shoulder arthroplasties) showed significant improvements in the Simple Shoulder Test score and Constant-Murley score (CMS) in various groups who underwent RSA as a form of revision surgery.

Various studies have described improvement in the Constant-Murley scores, in the short and medium term after RSA [26–28], and this improvement did not appear to be affected by patient demographics such as age or gender (Table 2). However, it appeared that in longer-term follow-up, the improvement in CMS may decrease, potentially due to a decline in range of motion over time [19,20,27]. A decline in CMS tends to be observed between medium- to long-term follow-up. Bacle et al. [19] noted that CMS improved from 23 to 63 at mid-term follow-up; however, this declined to 55 at 150 months. Favard et al. [20] also noted that CMS increased from 23.9 to 61.5 at 5 years; however, there is a drop to 56.76 at 9 years. In the study by Guery et al. [27], 88% of patient had a CMS of more than 30 at 72 months follow-up; however, this decreased to only 58% at 120 months.

3.3. Evolving concept of outcomes (MCID, SCB, PASS)

Outcome assessments of reverse shoulder arthroplasty (RSA) have evolved in recent years, with the development of various outcome scores. This variability between scoring systems posed challenges in creating practical guidelines for management. While statistically significant improvements in scores are typically expected after RSA, these improvements may not necessarily correspond with patients’ satisfaction and expectations. To address this, newer methods, such as minimal clinically important difference (MCID), substantial clinical benefit (SCB) and patient-acceptable symptomatic state (PASS) have been developed to quantify the beneficial value of shoulder arthroplasty (Table 3).

MCID is the smallest difference in score that patients perceive as beneficial and would necessitate a change in management in the absence of negative side effects or excessive cost [31], while substantial clinical benefit (SCB) refers to a level of significant improvement in a patient’s condition that is perceived as meaningful by the patients themselves [32]. Werner et al. found in a sample of patients with glenohumeral arthritis or rotator cuff tear arthropathy who underwent primary conventional total or reverse shoulder arthroplasty, those who experienced a nine-point or greater improvement in their American Shoulder and Elbow Surgeons (ASES) score demonstrated a clinically meaningful change in their condition and patients who experienced a 23-point or greater improvement in their ASES score demonstrated a substantial clinical benefit [29]. In a study by McLachlan et al. MCID was identified to be 3.7 based on Simple Shoulder Test Scores, and the study team found that 66% of the cohort of 80 RSA patients attained MCID after RSA [33].

PASS is defined as the highest level of symptom beyond which a patient would consider himself to be well. Chamberlain et al. [30] performed a study on PASS in 2017 and found that patients treated with shoulder arthroplasty consider Visual Analog Scale (VAS) pain score, the Simple Shoulder Test (SST) and American Shoulder and Elbow Surgeons (ASES) score of 1.5, 8.4 and 76 to be acceptable symptomatic states.

While there are growing number of papers describing MCID, SCB and PASS values for various functional outcomes, there is a paucity of studies on the attainment of MCID, SCB and PASS after RSA.

Table 2
Short- and medium-term outcomes of reverse shoulder arthroplasty (RSA) based on patient-reported outcome measures.

<table>
<thead>
<tr>
<th>Nature of Study</th>
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<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Review/Meta-Analysis</td>
<td>Bois et al. [13] 2020</td>
<td>JSES Int</td>
<td>43 studies (1041 shoulder arthroplasties), Significant improvements in the Simple Shoulder Test score and Constant-Murley score (CMS) in various groups who underwent RSA as a form of revision surgery.</td>
</tr>
<tr>
<td>Retrospective review</td>
<td>Bacle et al. [1] 2017</td>
<td>JBJS</td>
<td>191 RSAs, CMS improvement from 23 to 63 at mid-term but declined to 55 at 150 months (long-term)</td>
</tr>
<tr>
<td>Retrospective review</td>
<td>Guery et al. [27] 2006</td>
<td>JBJS</td>
<td>80 RSAs, Decline in number of patients with CMS &gt;30, from 88% to 58% as patients progressed from mid-term to long-term follow-up</td>
</tr>
<tr>
<td>Retrospective review</td>
<td>Favard et al. [20] 2011</td>
<td>CORR</td>
<td>527 RSAs, CMS increase from 23.9 to 61.5 at 5 years, but dropped to 56.76 at 9 years</td>
</tr>
</tbody>
</table>

Table 3
Newer concepts in defining outcomes post reverse shoulder arthroplasty (RSA).

<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal clinically important difference (MCID)</td>
<td>Smallest difference in score that patients perceive as beneficial and would necessitate a change in management in the absence of negative side effects or excessive cost</td>
<td>Werner et al. [29]: those who experienced a nine-point or greater improvement in their American Shoulder and Elbow Surgeons (ASES) score demonstrated a clinically meaningful change in their condition</td>
</tr>
<tr>
<td>Patient-acceptable symptomatic state (PASS)</td>
<td>Absolute threshold, beyond which patients consider themselves well and satisfied with treatment</td>
<td>Chamberlain et al. [30]: Visual Analog Scale (VAS) pain score, the Simple Shoulder Test (SST) and American Shoulder and Elbow Surgeons (ASES) score of 1.5, 8.4 and 76 considered acceptable symptomatic states</td>
</tr>
<tr>
<td>Substantial Clinical Benefit (SCB)</td>
<td>The level of significant improvement in a patient’s condition that is perceived as meaningful by the patients themselves</td>
<td>Werner et al. [29]: Patients who experienced a 23-point or greater improvement in their ASES score demonstrated a substantial clinical benefit.</td>
</tr>
</tbody>
</table>
4. Effect of surgical approach on outcomes

The 2 main approaches for RSA are the deltopectoral approach and the lateral approach. In the series by Sirveaux et al. [9] where lateral approach was performed in 58 shoulders, deltopectoral in 16 and transacromial in 3, they found no difference in CMS at a mean follow-up of 44.5 months. Gillespie et al. [34] conducted a retrospective study of 93 cases, of which 62 patients underwent lateral and 31 deltopectoral approaches, and found no significant differences in postoperative range of motion, scapular notching and position of glenoid baseplate at a time frame of approximately 3 years. Molet et al. [35] performed a comparative review involving 527 RSAs (300 deltopectoral, 227 lateral) and showed similar Constant-Murley scores. Aibinder et al. studied 109 patients who underwent RSAs (22 deltopectoral, 87 lateral) and found no statistically significant difference in range of motion, and pain scores between approaches at around the 3-year mark.

5. Implant survivorship and revision rates

Several studies have investigated the long-term survivorship of RSA implants. These studies have reported varying survival rates at different follow-up time points (Table 4).

<table>
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<tbody>
<tr>
<td>Retrospective study</td>
<td>Guery et al. [27]</td>
<td>JBJS (2006)</td>
<td>91 % implant survivorship at 10 years postoperatively. RSA for cuff tear arthropathy conferred better long-term outcomes than for other aetiologies</td>
</tr>
<tr>
<td>Retrospective Review</td>
<td>Bacle et al. [19]</td>
<td>JBJS (2017)</td>
<td>93 % Implant survivorship at 10 years postoperatively</td>
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<td>Retrospective Review</td>
<td>Favard et al. [20]</td>
<td>CORR (2011)</td>
<td>89 % implant survivorship at 10 years postoperatively</td>
</tr>
<tr>
<td>Retrospective Review</td>
<td>Chelli et al. [36]</td>
<td>J Clin Med (2022)</td>
<td>Revision RSA 80.9 % survivorship</td>
</tr>
<tr>
<td>Retrospective Review</td>
<td>Goldenberg et al. [37]</td>
<td>JSLS (2020)</td>
<td>75.7 % survivorship for patients aged &lt;60, compared to 94.3 % for patients aged above 80. Systematic review of 7 studies comprising 286 shoulders of patients &lt;65 years, implant survival rate of 99 % at 2 years, 91%–98 % at 5 years and 88 % at 10 years.</td>
</tr>
</tbody>
</table>

6. Revision rates and its leading causes (Table 5)

The reported revision rates after RSA range from 10.1 % to 13.4 % [18,38,39]. The main reasons for revision surgery after RSA were prosthetic instability (48 %), loosening or other issues with the humeral component (21 %) and infection (19 %) [40]. Despite increased revision rates in younger patients, studies have shown that RSA outcomes in younger populations below the age of 60 still confer improvement in function [41–44]. However, several studies have found that the majority of revisions occur in the early post-surgery period, with a decrease in the incidence of revision surgery thereafter. This is likely due to the fact that the most common causes of revision surgery, such as infection and mechanical failure (dislocation) tend to occur shortly after the initial surgery. For example, in a study by Bacle et al. [19], the revision rate was 12 % at an average follow-up of 150 months, with 8 of the revisions occurring in the first 2 years and another 8 occurring after 2 years. Infection was the most common cause of revision surgery in the first 2 years, while implant loosening was the most common cause in those who required revision after 2 years. Other studies have also found that infection is a leading cause of revision surgery, particularly in the first few years after the initial procedure. Frankie et al. reported a revision rate of 11.7 % in 60 prostheses at an average of 21.4 months [45], and found that in all cases requiring revision surgery, the porous surface of the glenoid baseplate showed no evidence of osseous ingrowth, leading them to conclude that the first two years after RSA is a critical period during which mechanical failure may occur if osseous ingrowth does not take place. Revision shoulder replacement surgery to address loosening of the polyethylene component was associated with a 17 % rate of mechanical failure in the glenoid. While this procedure can lead to improvements in pain and function, it is not always successful and requires further improvement in order to achieve better outcomes [46]. Table 5.

7. Pushing future boundaries

There have been an increase in innovative technologies for RSA. 3D preoperative planning software and patient-specific instrumentaion [48] are increasingly being used to assist with the placement of the glenoid component in total shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA). These tools are becoming more widely available commercially. Iannotti et al. [49] showed that using 3-D preoperative planning software in conjunction with standard instrumentation resulted in improved guide pin positioning compared to using
standard instrumentation with preoperative planning based on 2-D imaging, and Stubbig et al. [50] showed similar findings of more accurate positioning of the glenoidal baseplate in the axial scapular plane through 3D C-arm navigation.

Computer navigation during RSA implantation is also an area of interest. In a study by Wang et al. [51], it was demonstrated that the group with RSA via navigation took less surgical time than the non-navigated group. The authors also suggested that 8 operative cases were required to achieve proficiency in intraoperative computer navigation of the glenoid component, which did not appear to be a large number. Holzgrefe et al. demonstrated via a matched cohort study of 226 shoulders, that navigated and non-navigated RSAs yielded similar rates of improvement in terms of motion and functional outcome scores. Notching and reoperation were more common in non-navigated shoulders, although the results were not statistically significant [52].

Beyond the conventional RSA, the innovations include use of artificial intelligence and robotics. Kunze et al.’s team managed to train an automated deep learning (DL) algorithm using 3060 postoperative images from patients who underwent RSA, to successfully classify 22 different implants from eight manufacturers with an accuracy of 97.1 % and an area under the multi-class receiver-operator characteristic curve (AUROC) of 0.994–1.000 [53], while Darwood et al. developed a novel intraoperative robotics platform comprising a tableside robot equipped with a 3D optical scanner, and robotic drill, to rapidly create a mould of the glenoid joint surface intraoperatively, in order to improve glenoid component accuracy [54].

The current focus of studies utilizing these modalities are still in their infancy, but the potential for significant advancements in RSA is apparent. However, significant challenges remain, including ensuring the safety and efficacy of these new technologies, developing appropriate training for surgeons, and addressing regulatory and ethical concerns. As research in this field progresses, we can look forward to a future in which RSA becomes an even more effective procedure.

8. Conclusion

RSA has revolutionized the treatment of cuffed arthropathy, which previously did not have a suitable solution. Patient-reported outcome measures and patient satisfaction rates are high in the short and mid-term follow-up but may decline in the long-term, with the majority of patients experiencing improvement in pain scores and better function. Revision rates range between 5 and 12 % in the long term and more studies are needed to validate the long-term efficacy of RSA.

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Disclosure

The authors of this manuscript have nothing to disclose that would bias our work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[10] Kim H, Kim CH, Kim M, Lee W, Jeon IH, Lee KW, et al. Is reverse total shoulder arthroplasty via navigation taken less surgical time than the non-navigated group? The authors also suggested that 8 operative cases were required to achieve proficiency in intraoperative computer navigation of the glenoid component, which did not appear to be a large number.

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