JSES International 6 (2022) 587–595

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

The recovery curve of anatomic total shoulder arthroplasty for primary glenohumeral osteoarthritis: midterm results at a minimum of 5 years

Burak Altintas, MD[a,b], Marilee P. Horan, MPH[a], Grant J. Dornan, MS[a], Jonas Pogorzelski, MD, MHBA[a,c], Jonathan A. Godin, MD, MBA[a,d], Peter J. Millett, MD, MSc[a,d,*]

[a]Steadman Philippon Research Institute, Vail, CO, USA
[b]Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA
[c]Department of Orthopaedic Sports Medicine, Hospital Rechts der Isar, Technical University of Munich, Munich, Germany
[d]The Steadman Clinic, Vail, CO, USA

ARTICLE INFO

Keywords:
Anatomic shoulder
Arthroplasty
Glenohumeral osteoarthritis
Longitudinal recovery curve
Outcomes
Shoulder arthritis

Level of evidence: Level IV; Case Series; Treatment Study

Background: Excellent results have been reported for anatomic total shoulder arthroplasty (TSA) for the treatment of primary glenohumeral osteoarthritis (GHOA). We aim to assess the recovery curve and longitudinal effects of time, age, sex, and glenoid morphology on patient-reported outcomes (PROs) after primary anatomic TSA for primary GHOA.
Methods: Patients who underwent primary anatomic TSA over 5 years ago were included: Short-Form 12 Physical Component Summary, American Shoulder and Elbow Surgeons scores, Quick Disabilities of the Arm Shoulder and Hand Score, Single Assessment Numeric Evaluation, and patient satisfaction were assessed. Linear mixed-effects models were used to model progression in PROs longitudinally. Unadjusted models and models controlling for sex and age were constructed.
Results: Eighty-one patients (91 shoulders) were included. Significant improvements from the preoperative period to 1 year postoperatively in the median American Shoulder and Elbow Surgeons (48 to 93; $P < .001$), Quick Disabilities of the Arm Shoulder and Hand Score (42 to 11; $P < .001$), Single Assessment Numeric Evaluation (50 to 91; $P < .001$), and Short-Form 12 Physical Component Summary (35 to 53; $P = .004$) scores were noted. No significant decrease was observed for any of the outcome scores. Median satisfaction at the final follow-up was 10 out of 10. At 1, 2, 3, 4, 5, 6, and 7 years postoperatively, 77%, 64%, 79%, 57%, 86%, 56%, and 78% of patients, respectively, reported sports participation equal to or slightly below preinjury level. There was no association between the glenoid morphology and functional outcomes.
Conclusion: Patients undergoing anatomic TSA for primary GHOA showed excellent improvement in PROs and satisfaction in the first year, and these results were maintained postoperatively for a minimum of 5 years. Age- and sex-adjusted models or glenoid morphology did not substantially alter any trends in PROs postoperatively.

Primary glenohumeral osteoarthritis (GHOA) can lead to significant disability. Young and active patients may benefit from nonoperative treatment including nonsteroidal anti-inflammatory medication, physical therapy, and intraarticular corticosteroid or hyaluronic acid injection[4,6,24,44] or arthroscopic joint-preserving procedures such as comprehensive arthroscopic management.[25-27] However, total shoulder arthroplasty (TSA) is still the preferred treatment strategy in most cases, particularly in older individuals and in those with joint incongruity, severe joint space narrowing, and glenoid deformity.[25-27] In these cases, anatomic TSA offers

This study was approved by the institutional review board of Vail Valley Hospital, IRB #2017-04. Research performed at the Steadman Philippon Research Institute, Vail, CO.

*Corresponding author: Peter J. Millett, MD, MSc, Steadman Philippon Research Institute, The Steadman Clinic, 181 West Meadow Drive, Suite 400, Vail, CO 81657, USA.
E-mail address: drmillett@thesteadmanclinic.com (P.J. Millett).

https://doi.org/10.1016/j.jseint.2022.04.011

significant improvements in pain relief, function, and quality of life.[8,17,32,34,43] Over the past decade, the incidence of TSA for the treatment of primary GHOA has rapidly grown, making longer term follow-up studies to evaluate patient outcomes, safety, and implant longevity essential.[18]

There is general consensus in the literature that patients with GHOA benefit significantly from TSA when it is performed correctly.[17,33,42] While the majority of the aforementioned published studies report clinical results preoperatively and at the final follow-up, only very few studies analyze the clinical course of the recovery with an anatomic TSA design.[34,35] Studying this recovery curve helps clinicians and patients understand how pain and function change following TSA, as well as how long results are maintained. Moreover, understanding the variables that influence longitudinal outcomes is helpful to counsel patients and to manage expectations.

Thus, the aim of this study was to assess the specific recovery curve and the longitudinal effects of time, age at surgery, and sex on patient-reported outcomes (PROs) and pain after primary anatomic TSA for primary GHOA with a minimum of 5 years of follow-up. The hypothesis was that pain and PROs would improve following anatomic TSA and that these results would be maintained over time. In addition, we postulated that advanced age, female sex, and B2 glenoid morphology would have lower outcome scores.

Materials and methods

Study design

This was an institutional review board-approved (2017-04) retrospective outcomes study using prospectively collected data stored in a patient registry. All patients who underwent primary anatomic TSA for idiopathic GHOA by the senior surgeon (P.J.M.), who were at least 5 years out from surgery, were eligible for inclusion. Patients underwent TSA between December 2005 and October 2012. Patients with nonidiopathic osteoarthritis, for example, resulting from rheumatoid arthritis, previous glenohumeral dislocations, or fractures of either the proximal humerus or glenoid, were excluded. Moreover, patients were excluded from analysis if they refused to participate or died before the minimum follow-up period.

Failure and complications were recorded. Failure was defined as the need for revision TSA. This included revision surgery for component loosening, rotator cuff tear that necessitated conversion to reverse TSA (RTSA), or prosthetic loosening. Complications were defined as infection, wound dehiscence, nerve damage, stiffness requiring surgery, rotator cuff tendon tears that required repair, and persistent pain.

Shoulder-specific PRO scores were collected both preoperatively and postoperatively in yearly intervals and included the American Shoulder and Elbow Surgeons score (ASES), Quick Disabilities of the Arm Shoulder and Hand score (QuickDASH), Single Assessment Numeric Evaluation (SANE), and the overall general health Short Form-12 Physical Component Summary (SF-12 PCS) score, as well as pain levels according to the Visual Analog Scale (VAS). In addition, both subscales of the ASES score were separately recorded. Postoperative satisfaction scores were also collected (10-point scale; 1 = highly unsatisfied; 10 = highly satisfied). Additional questions assessed patients' postoperative ability to return to specific recreational activities.

Glenoid morphology was categorized retrospectively according to the Walch classification for analysis based on preoperative axial magnetic resonance imaging or computed tomography scans.[38]

Surgical technique

The senior surgeon (P.J.M.) performed the surgeries with an anatomic TSA implant (Univers II; Arthrex, Inc., Naples, FL, USA). After the combination of a peripheral nerve block and general anesthesia, the patient was placed in the beach chair position using a pneumatic arm holder. A standard deltopectoral approach was utilized. The biceps tendon was released for tenodesis later. A lesser tuberosity osteotomy was used to remove the subscapularis, and the humeral head was exposed.[30] After removal of osteophytes and release of capsular contractures, the humeral head was osteotomized anatomically in the native version and inclination. The glenoid was then exposed, and the labrum and biceps anchor were removed. Additional anterior and inferior capsular releases were performed. The glenoid was then prepared and reamed to achieve a concentric fit of the prosthetic glenoid and to achieve the desired glenoid version. In B2 glenoids, corrective reaming was used to antevert the glenoid as much as the implant could tolerate to ensure that the pegs remained within the glenoid vault, based on preoperative 3-D imaging planning. An all-poly glenoid component with hybrid 2 pegs superiorly and a keel inferiorly (Arthrex, Inc., Naples, FL, USA) was cemented in place after the cement was pressurized. Next, the proximal humerus was reamed and broached to the appropriate size, and the stemmed humeral implant was inserted. If the bone quality was good, a short-stem humeral implant (Arthrex, Inc., Naples, FL, USA) was used (Fig. 1). Finally, the humeral head component was sized and inserted with the appropriate eccentricity to match the native head geometry. At this point, the shoulder was reduced and tested for stability. The subscapularis and lesser tuberosity were repaired utilizing #5 nonabsorbable sutures which were passed through the subscapularis tendon medial to the lesser tuberosity bone fragment, through the lesser tuberosity of the proximal humerus, and around the stem prior to final seating of the humeral implant, as has been described by Ponce et al.[30] The rotator interval was only closed laterally. The long head of the biceps tendon was tenodesed at the level of the pectoralis major tendon with #2 nonabsorbable sutures. The wound was then thoroughly irrigated and closed in a standard layered fashion. A postoperative rehabilitation program was initiated immediately as has been described by Wilcox et al.[41] Passive range of motion was begun on the first postoperative day with an external rotation limit of 30° for the first 3 weeks postoperatively. A sling was used for protection. At 3 weeks postoperatively, full passive and active range of motion were permitted, and the sling was discontinued. Return to full activities was permitted when full range of motion and strength were obtained. This was typically achieved by 4 months postoperatively.

Statistical analysis

The primary aim of this study was to characterize the recovery trajectory of patients following TSA as assessed by several PRO scores. To fully utilize the longitudinal nature of the available data and to allow for differential missing annual observation patterns among patients, random-intercepts linear mixed-effects (LMEs) models were constructed. Follow-up time for each collected questionnaire was rounded to the nearest anniversary year of surgery, and follow-up time was entered into the models as an ordinal variable. To ensure a sufficient patient count at each follow-up group, postoperative follow-up years were categorized as 1, 2, 3, 4, 5, 6, or 7+, where the single furthest follow-up available for a given patient beyond 7 years postoperatively was used. This framework adjusted for each patient's baseline health status and allowed for pairwise comparison among the baseline and each postoperative time point via Tukey's method. As a sensitivity analysis, additional otherwise

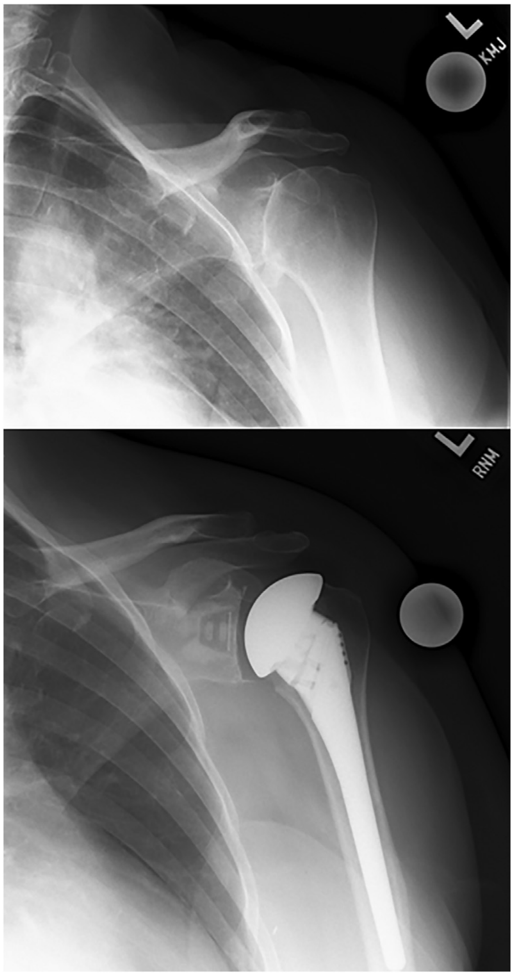

Figure 1 Left shoulder with advanced glenohumeral osteoarthritis before and after total shoulder arthroplasty.

identical models were created that adjusted for age and sex at surgery. Statistical power for effect estimates within these models was protected by the rule of thumb that a maximum of 1 model parameter should be included for every 10 unique patients. We reported our primary follow-up rate to be the percent of patients eligible for analysis for whom minimum 5-year outcomes were acquired, but the LME models utilized outcome data from all eligible patients, even when the furthest follow-up was less than 5 years. Residual diagnostics were assessed to ensure model fit and that model assumptions were adequately met. The ordinal variables patient satisfaction and return to activity level were not well suited for this parametric LME modeling approach, and thus, their longitudinal behaviors were reported descriptively. The Kruskal-Wallis test was used to compare average baseline and postoperative PRO values among glenoid morphology (Walch) classification types. Summary statistics were reported for subjective outcome scores using medians and interquartile ranges (IQR). The statistical programming language R version 3.4.0 was used to produce all plots and analyses (R Core Team, Vienna, Austria, with additional package lme4; access date November 17, 2017).[1,31]

Results

Between December 2005 and October 2012, the senior surgeon (P.J.M.) performed 240 shoulder arthroplasties, 98 (86 patients) of which met the inclusion criteria. Two patients (3 shoulders) died, and 4 patients refused to participate. Ninety-one shoulders (81 patients; 24 women and 57 men) remained in the final study population. The mean age was 63 years (range, 18-80 years), and minimum 5-year follow-up data were obtained for 74 of 91 (81%) shoulders. Among the 17 shoulders lacking complete 5-year follow-up data, 13 had follow-up for at least 1 earlier postoperative time point, and these data were used in the longitudinal modeling. Details on inclusion and exclusion criteria are outlined in Fig. 2.

Three shoulders failed, and 4 additional shoulders experienced complications requiring further surgery. Among the failures, 1 patient was revised to RTSA for rotator cuff tear, and 1 patient was revised to RTSA for chronic instability. One patient required revision TSA due to glenoid component loosening. Of the 4 patients requiring further surgery, 1 patient underwent revision surgery with subscapularis repair and lysis of adhesions, 1 patient underwent lysis of adhesions alone, and 2 patients underwent surgical irrigation and débridement for superficial infections, neither of whom had to have their implants removed and had good long-term outcomes (Fig. 2).

Clinical outcomes

Subjective PROs were available for 87%, 55%, 48%, 56%, 40%, 36%, 27%, and 45% of patients at baseline, 1, 2, 3, 4, 5, 6, and 7+ years after surgery, respectively. LME modeling found significant improvements from preoperative period to 1 year postoperatively in the median [IQR] ASES (48 [37-60] to 93 [83-98]; $P < .001$), QuickDASH (42 [34-59] to 11 [5-25]; $P < .001$), SANE (50 [45-64] to 91 [68-99]; $P < .001$), and SF-12 PCS (35 [31-40] to 53 [46-57], $P = .004$) scores. Median (IQR) scores at 5 years postoperatively were 92 (81-97) for ASES, 11 (7-27) for QuickDASH, 89 (82-94) for SANE, and 50 (39-55) for SF-12 PCS.

Every PRO score maintained a statistically significant improvement over baseline at every postoperative time point between 1 and 7 years. Moreover, comparisons among postoperative time points (1, 2, 3, 4, 5, 6, or 7 years) did not show any statistically significant differences for any of the 4 PROs. Fig. 3 displays observed median, quartiles, and ranges at baseline and each postoperative time point for ASES, QuickDASH, SANE, and SF-12 PCS. Median satisfaction after surgery was 10 out of 10 points at every postoperative time point except at 5 years, when the median satisfaction was 9 (Fig. 4).

Age- and sex-adjusted models did not substantially alter any trends in PROs during the 7 years after surgery, compared to the unadjusted models. Increased patient age at surgery was significantly associated with a higher ASES score (slope estimate = +0.21 per year of age, $P = .046$), holding sex and length of follow-up constant. Males exhibited lower QuickDASH scores than females (estimate = −6.95, $P = .025$), holding age and length of follow-up constant. SF-12 PCS and SANE scores were not significantly associated with either age or sex (all $P > .05$).

LME modeling found significant improvements from the preoperative period to 1 year postoperatively in the median [IQR] pain levels according to VAS (5 [2-7] to 0 [0-1]; $P < .001$). The median (IQR) VAS at 5 years postoperatively was 0 (0-2) (Fig. 5).

Patient-reported functional evaluation

Using a subjective questionnaire, patients who participate in sports were asked the following question: “With regard to your shoulder, at what grade can you now participate in sports?”. Preoperatively, 91% of patients reported participation at least moderately below the preinjury level. At 1, 2, 3, 4, 5, 6, and 7+ years postoperatively, 77%, 64%, 79%, 57%, 86%, 56%, and 78% of

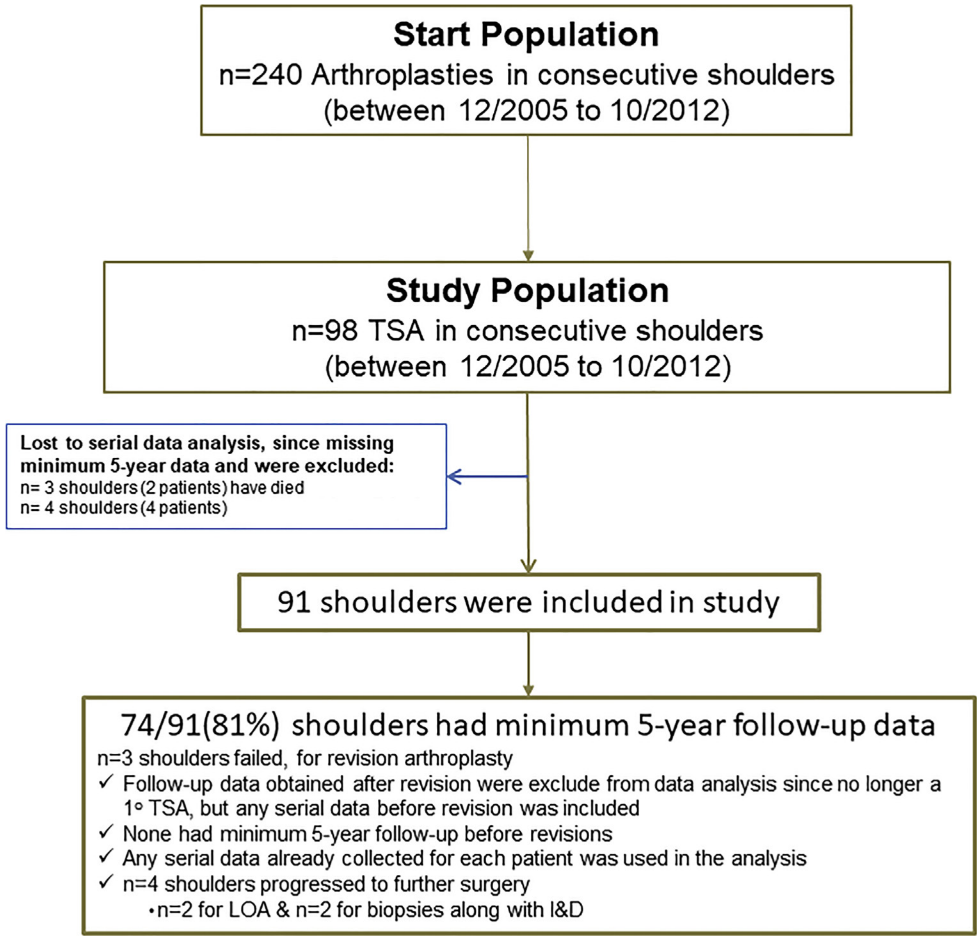

Figure 2 Flow chart visualizing the patient population for this study after accounting for inclusion and exclusion criteria, clinical failures, and those lost to follow-up. Patients progressing to another arthroplasty (RTSA or revision TSA) were defined as clinical failures. *TSA*, total shoulder arthroplasty; *RTSA*, reverse total shoulder arthroplasty; *LOA*, lysis of adhesions; *I&D*, irrigation and debridement.

responding patients reported participation equal to or slightly below their preinjury level, respectively (Fig. 6).

Patients were also asked to evaluate the difficulty of usual activities relative to their shoulder function. At baseline, 87%, 96%, 97%, and 74% reported at least some difficulty performing their usual work, usual recreational activities, carrying 20 pounds at their side, and performing their usual sports, respectively. Across each of the 7 follow-up time periods, 72%-90%, 63%-84%, 50%-79%, and 62%-78% reported normal function for the same 4 activities, respectively (Fig. 7).

Effect of glenoid morphology on postoperative outcome

Thirty-seven patients showed concentric glenoid wear with A1 glenoids according to the Walch classification. Eighteen patients had A2 glenoids, 13 patients had B2 glenoids, and 9 patients had B1 glenoids. Surprisingly, there was no statistically significant association between the glenoid morphology and functional outcomes either preoperatively or at the furthest follow-up time point postoperatively.

Discussion

The main finding from this study is that patients undergoing anatomic TSA for primary GHOA showed excellent improvement in their PROs and satisfaction in the first year, and these results were maintained postoperatively for a minimum of 7 years. Moreover, SF-12 PCS and SANE scores were not significantly associated with either age or sex. Men exhibited significantly lower QuickDASH scores than women, while increased patient age at surgery was significantly associated with higher ASES scores. Glenoid morphology did not seem to play a major role in PROs in this cohort at up to 7 years of clinical follow-up.

These results are consistent with the previous report by Raiss et al showing clinical improvement after TSA, plateauing at 1 year postoperatively and remaining stable without substantial worsening for 8 years.[34] The same has been shown by Razmjou et al who showed that the most significant improvements in disability, physical symptoms, and range of motion were made by 6 months following TSA. In their study, the improvements in ASES and relative Constant Murley scores continued up to 12 months and then began to plateau.[35] The current study shows the trajectory of recovery after TSA in an active population. This information is important when communicating the expected timeframe for maximal improvement to patients and when setting realistic expectations and appropriate postoperative goals.

The results of this study are consistent with other published series in that there was prolonged pain relief and functional improvement following TSA.[5,7,16,17,35] For example, in a recent study of 67 patients who underwent TSA, the ASES score improved from 37.9 to 78.8 after 2 years of follow-up.[37] In another study, Eichinger et al reported a postoperative ASES of 78.1 in patients younger than

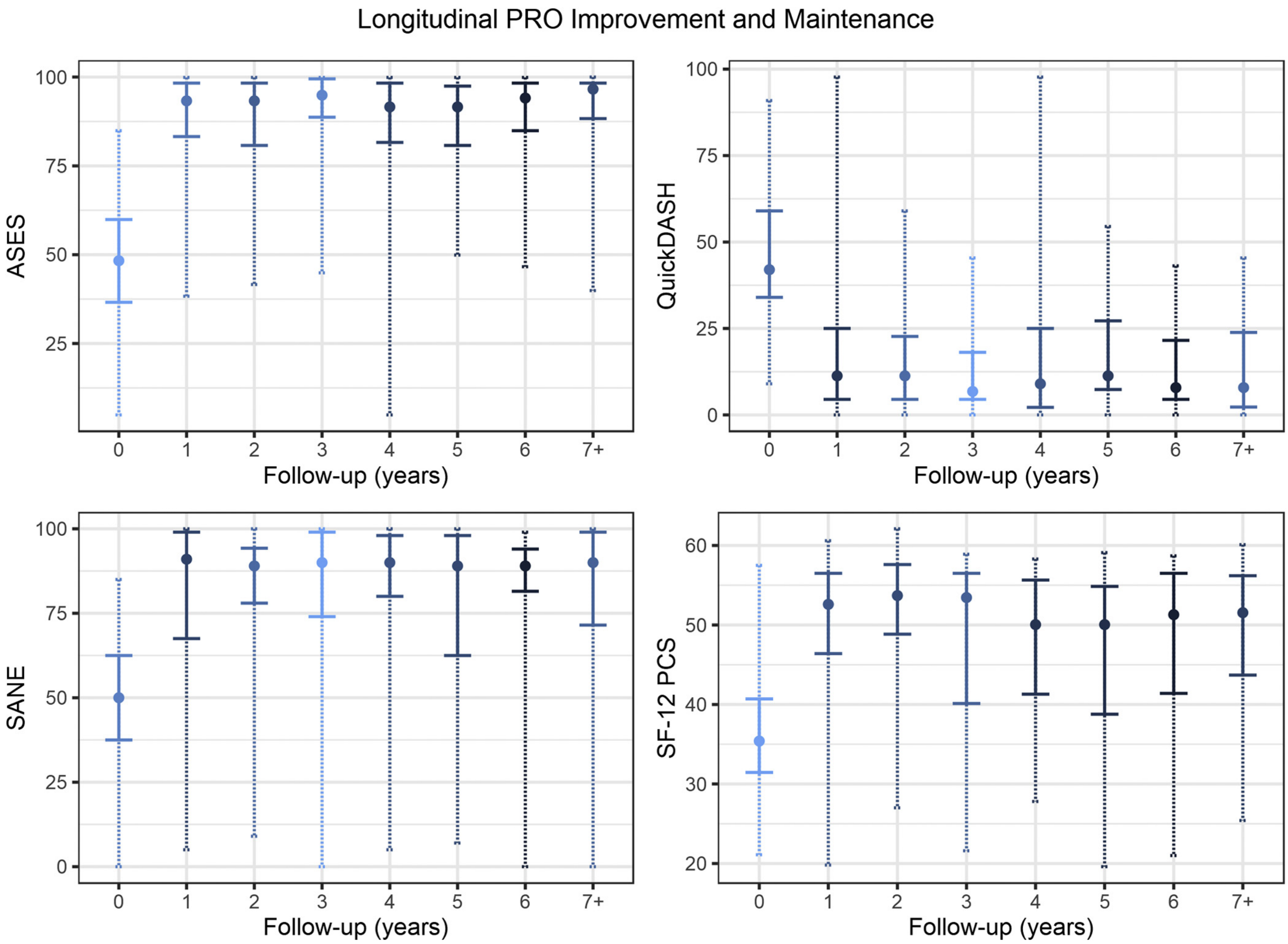

Figure 3 Longitudinal PRO scores. Time 0 is presurgical assessment. *Dots* represent median, *solid error bars* represent interquartile range (first quartile—third quartile), and *dashed error bars* represent range (minimum-maximum). *Shade of blue* represents sample size for given time point, according to legend scale. *PRO*, patient-reported outcome; *ASES*, American Shoulder and Elbow Surgeons; *QuickDASH*, Quick Disabilities of the Arm Shoulder and Hand Score; *SANE*, Single Assessment Numeric Evaluation; *SF-12 PCS*, Short-Form 12 Physical Component Summary.

50 years after a mean follow-up of 4.9 years and 95% survival.[11] Furthermore, Favard et al showed a significant increase in Constant score (from 30.6 to 60.9) in 72 who underwent TSA, with an 11% complication rate after a minimum follow-up of 8 years.[12] Finally, the patients in another study reached an ASES score of 71.5 when a metal-back glenoid component was used for TSA after a mean follow-up of 44 months.[10]

In the present study, we observed significantly lower QuickDASH scores (better outcome) in men than in women. These results are in concordance with a previous study, which reported better outcomes for male patients.[9] However, that study had a heterogenous collection of patients with various conditions ranging from primary to rheumatoid osteoarthritis and with various procedures such as primary and revision cases including TSA and hemiarthroplasty unlike the present study which only included primary GHOA.[9] In the present study, with the numbers available, there were no differences across sexes for the other PROs which were measured. Another study reported outcomes following hemiarthroplasty and showed improved outcomes for both sexes without significant differences.[13] It should be noted that due to the variety of indications for TSA and the variety of prosthetic designs used, comparison between the present study and the results of other published studies can be difficult. Leschinger et al reported outcomes after TSA for primary GHOA and could not detect any significant differences between sexes as well.[20] None of these studies utilized the scores used in the current study, so a direct comparison may be difficult.

In the present study, age did affect ASES scores, and interestingly increasing patient age at surgery was significantly associated with higher ASES scores. This may be due to the large influence pain plays in the ASES score and the effectiveness of TSA in alleviating pain. With the numbers available, there were no differences across age for the other PROs which were measured. These results are also in concordance with previous studies.[9,13,20] It has been stated that global health measures such as the SF-12 may demonstrate an inferior responsiveness to changes in a patient's upper extremity functionality compared with shoulder-specific measures. While another study showed only modest improvement in SF-12 score (from 36.0 to 40.6), our patients had significant improvements.[36] Iriberri et al found no significant differences in Constant scores comparing older with younger patients.[15] This finding could be attributed to the lower demands on shoulder activity in older patients.

In contrast to the findings in some prior studies,[7,21,28,39] preoperative glenoid morphology was not associated with worse outcomes in the present study. This may be secondary to the effectiveness of the surgical technique in managing the potentially adverse effects of these pathoanatomic factors.[23] Matsen et al showed no association between preoperative glenoid version or

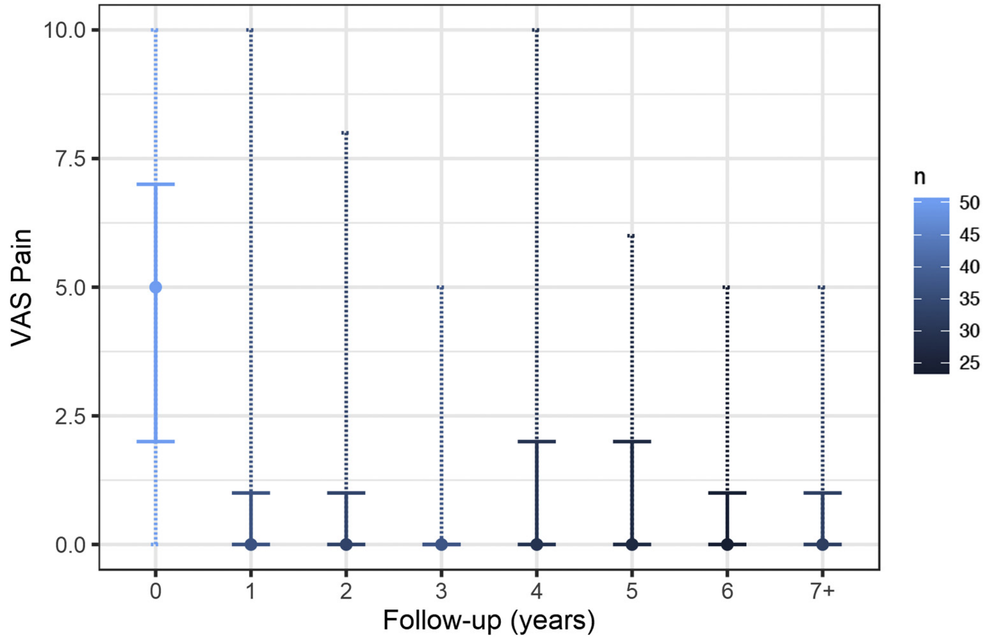

Figure 4 Longitudinal patient satisfaction with surgical outcome. *Dots* represent median, *solid error bars* represent interquartile range (first quartile—third quartile), and *dashed error bars* represent range (minimum-maximum). *Shade of blue* represents sample size for the given time point, according to legend scale.

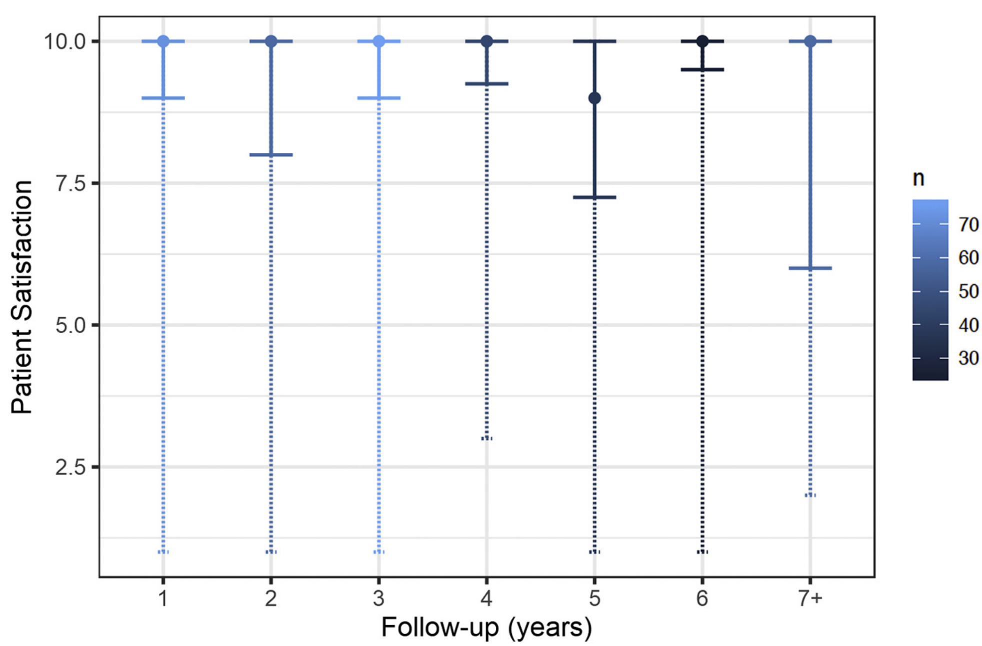

Figure 5 Longitudinal pain levels according to VAS. *Dots* represent median, *solid error bars* represent interquartile range (first quartile—third quartile), and *dashed error bars* represent range (minimum-maximum). *Shade of blue* represents sample size for the given time point, according to legend scale. *VAS*, Visual Analog Scale.

posterior decentering of the humeral head on the glenoid and the outcomes.[23] Petri et al analyzed 95 shoulders following TSA at a mean follow-up of 3 years and showed similar outcomes between concentric and eccentric glenoid wear.[29] Hussey et al showed similar clinical improvements in patients with concentric and eccentric glenoid wear in GHOA treated with TSA at a mean follow-up of 51 months.[14] However, patients with preoperative eccentric glenoid wear had a significantly higher rate of gross glenoid component loosening, raising concerns that this may translate to a higher rate of revision in the eccentric group after longer follow-up.[14] Longer term follow-up on the subjects from this series who underwent corrective reaming for B2 glenoids will be interesting.

Another important finding of our study was the high rate of return to activity after TSA. Despite the expected decrease in activity levels with the slow progression of osteoarthritis, preoperatively, 91% of patients reported participation at least moderately below the preinjury level while the majority could participate equal to or slightly below their preinjury level postoperatively with 71%

JSES International 6 (2022) 587–595

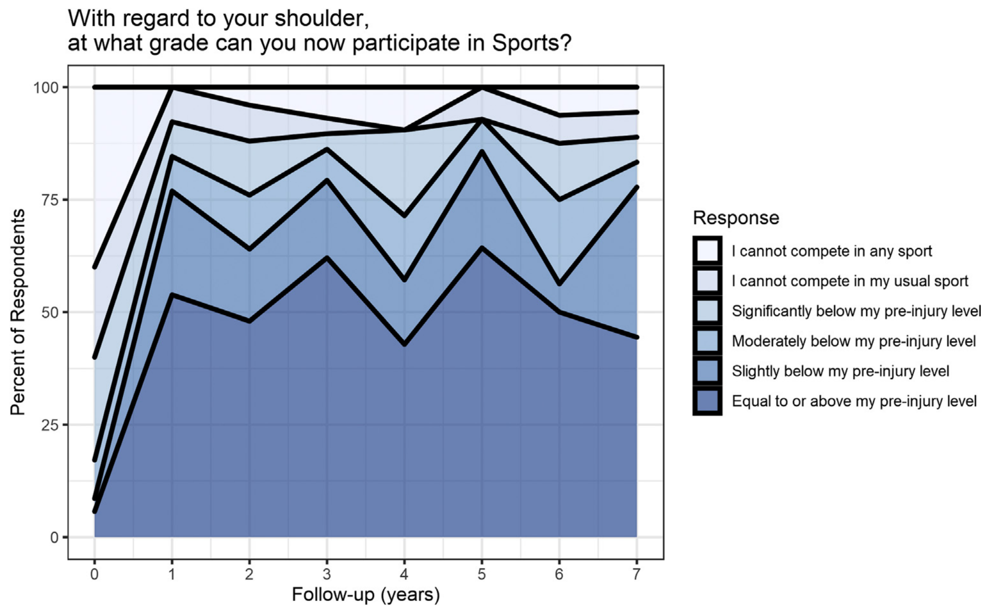

Figure 6 Longitudinal response percentages for sports participation.

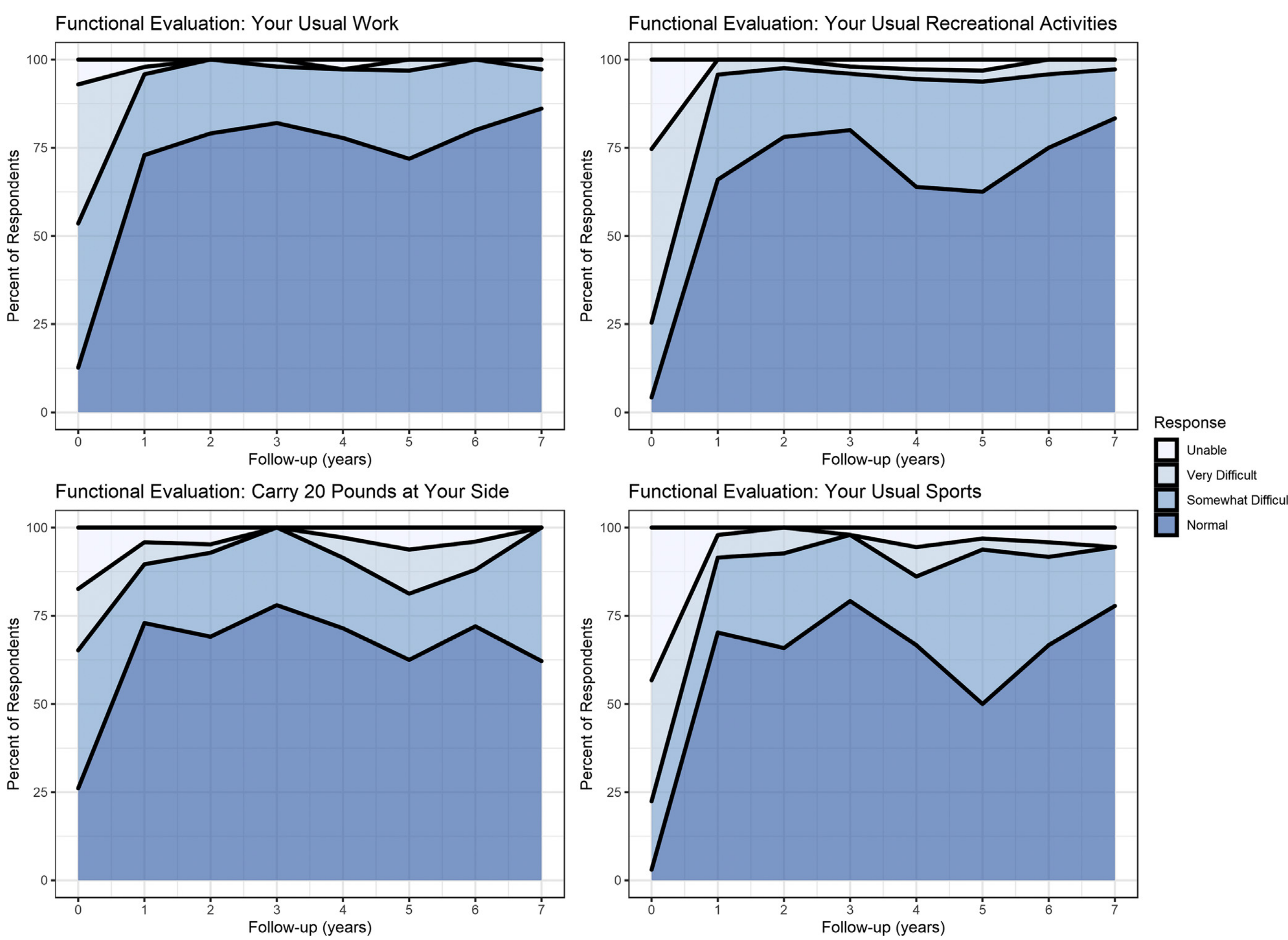

Figure 7 Longitudinal response percentages for several patient-reported functional evaluations.

achieving this at 7 years postoperatively. This is consistent with the study by Mannava et al who showed that return to recreational sports can be achieved at participation levels that are comparable with preoperative levels after a minimum of 2 years.[22] Similar results were shown by another study with an overall sports participation of 57% following TSA at the final mean follow-up of 6.2 years.[3] Moreover, the current study showed improvement in performing usual activities following TSA with 63%-84% reporting normal function in recreational activities and 72%-90% in usual work across each of the 7 follow-up time periods. These results support the previous literature that TSA allows for the participation in work and sports.[19] While Baumgarten et al showed that shoulder arthroplasty patients in general have significant improvements in their quality of life but only small improvements in activity level,[2] Wang et al suggested that patients undergoing shoulder arthroplasty can maintain an active lifestyle with moderate to high frequencies of participation after surgery.[40]

Limitations

This study has several limitations. First, this study was performed retrospectively. Furthermore, this study is comprised of a single surgeon's experience at a referral practice with highly motivated and active patients, so the findings may not apply to other surgical practices or patient populations. This study involved an anatomical implant design, so the results may not be generalizable to other prosthetic designs. Although we were able to obtain minimum 5-year follow-up on 74 out of 91 patients (81%), it was not always possible to get PROs or sports participation data on a yearly basis from every patient. Therefore, we used statistical models to overcome this problem. Finally, we were not able to obtain radiographic images on all patients at the final follow-up. We did however know the status for all patients as to whether the implant had survived or not.

Conclusion

Patients undergoing anatomic TSA for primary GHOA showed excellent improvement in PROs and satisfaction in the first year, and these results were maintained postoperatively for a minimum of 5 years. Age- and sex-adjusted models or glenoid morphology did not substantially alter any trends in PROs postoperatively.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: Burak Altintas had his research position at the Steadman Philippon Research Institute funded by AGA fellowship (German Society for Arthroscopic Surgery). This is a yearly position supported by a grant from Arthrex, Inc. Marilee P. Horan received research support from the Steadman Philippon Research Institute, which is a 501(c)(3) nonprofit institution supported financially by private donations and corporate support from the following entities: Smith & Nephew, Inc.; Arthrex, Inc.; Siemens; and Ossur Americas, Inc.
Grant J. Dornan received research support from the Steadman Philippon Research Institute, which is a 501(c)(3) nonprofit institution supported financially by private donations and corporate support from the following entities: Smith & Nephew, Inc.; Arthrex, Inc.; Siemens; and Ossur Americas, Inc.
Jonas Pogorzelski received research support from the Steadman Philippon Research Institute, which is a 501(c)(3) nonprofit institution supported financially by private donations and corporate support from the following entities: Smith & Nephew, Inc.; Arthrex, Inc.; Siemens; and Ossur Americas, Inc.
Jonathan A. Godin report support Supreme Orthopedics, grants and educational support from Arthrex, food or beverage from Smith & Nephew, Research grants from the Department of Justice (DOJ) as funded studies at SPRI. And consulting fees from Bioventus, outside of the submitted work. He received research support from the Steadman Philippon Research Institute, which is a 501(c)(3) nonprofit institution supported financially by private donations and corporate support from the following entities: Smith & Nephew, Inc.; Arthrex, Inc.; Siemens; and Ossur Americas, Inc.
Peter J. Millett receives royalties and consultant payments from Arthrex, Inc.; Medbridge; and Springer Publishing which is not related to the subject of this work. Dr Millett has stock in VuMedi. He received research support from the Steadman Philippon Research Institute, which is a 501(c)(3) nonprofit institution supported financially by private donations and corporate support from the following entities: Smith & Nephew, Inc.; Arthrex, Inc.; Siemens; and Ossur Americas, Inc.

References

1. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. J Stat Softw 2015;67:251-64. https://doi.org/10.18637/jss.v067.i01.
2. Baumgarten KM, Chang PS, Dannenbring TM, Foley EK. Does total shoulder arthroplasty improve patients' activity levels? J Shoulder Elbow Surg 2018;27:1987-95. https://doi.org/10.1016/j.jse.2018.03.028.
3. Bülhoff M, Sattler P, Bruckner T, Loew M, Zeifang F, Raiss P. Do patients return to sports and work after total shoulder replacement surgery? Am J Sports Med 2015;43:423-7. https://doi.org/10.1177/0363546514557940.
4. Carfagno DG, Ellenbecker TS. Osteoarthritis of the glenohumeral joint. Phys Sportsmed 2002;30:19-30. https://doi.org/10.3810/psm.2002.04.253.
5. Carter MJ, Mikuls TR, Nayak S, Fehringer EV, Michaud K. Impact of total shoulder arthroplasty on generic and shoulder-specific health-related quality-of-life measures: a systematic literature review and meta-analysis. J Bone Joint Surg Am 2012;94:e1271-9. https://doi.org/10.2106/JBJS.K.00204.
6. Cole BJ, Yanke A, Provencher MT. Nonarthroplasty alternatives for the treatment of glenohumeral arthritis. J Shoulder Elbow Surg 2007;16:S231-40. https://doi.org/10.1016/j.jse.2007.03.011.
7. Denard PJ, Raiss P, Sowa B, Walch G. Mid- to long-term follow-up of total shoulder arthroplasty using a keeled glenoid in young adults with primary glenohumeral arthritis. J Shoulder Elbow Surg 2013;22:894-900. https://doi.org/10.1016/j.jse.2012.09.016.
8. Deshmukh AV, Koris M, Zurakowski D, Thornhill TS. Total shoulder arthroplasty: long-term survivorship, functional outcome, and quality of life. J Shoulder Elbow Surg 2005;14:471-9. https://doi.org/10.1016/j.jse.2005.02.009.
9. Donigan JA, Frisella WA, Haase D, Dolan L, Wolf B. Pre-operative and intra-operative factors related to shoulder arthroplasty outcomes. Iowa Orthop J 2009;29:60-6.
10. Edwards TB, Kadakia NR, Boulahia A, Kempf J-F, Boileau P, Némoz C, et al. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. J Shoulder Elbow Surg 2003;12:207-13. https://doi.org/10.1016/S1058-2746(02)86804-5.
11. Eichinger JK, Miller LR, Hartshorn T, Li X, Warner JJP, Higgins LD. Evaluation of satisfaction and durability after hemiarthroplasty and total shoulder arthroplasty in a cohort of patients aged 50 years or younger: an analysis of discordance of patient satisfaction and implant survival. J Shoulder Elbow Surg 2016;25:772-80. https://doi.org/10.1016/j.jse.2015.09.028.
12. Favard L, Katz D, Colmar M, Benkalfate T, Thomazeau H, Emily S. Total shoulder arthroplasty—arthroplasty for glenohumeral arthropathies: results and complications after a minimum follow-up of 8years according to the type of arthroplasty and etiology. Orthop Traumatol Surg Res 2012;98:S41-7. https://doi.org/10.1016/j.otsr.2012.04.003.
13. Hettrich CM, Weldon E, Boorman RS, Parsons IM, Matsen FA. Preoperative factors associated with improvements in shoulder function after humeral hemiarthroplasty. J Bone Joint Surg Am 2004;86-A:1446-51. https://doi.org/10.2106/00004623-200407000-00012.
14. Hussey MM, Steen BM, Cusick MC, Cox JL, Marberry ST, Simon P, et al. The effects of glenoid wear patterns on patients with osteoarthritis in total shoulder arthroplasty: an assessment of outcomes and value. J Shoulder Elbow Surg 2015;24:682-90. https://doi.org/10.1016/j.jse.2014.09.043.
15. Iriberri I, Candrian C, Freehill MT, Raiss P, Boileau P, Walch G. Anatomic shoulder replacement for primary osteoarthritis in patients over 80 years. Acta Orthop 2015;86:298-302. https://doi.org/10.3109/17453674.2015.1006036.
16. Jacobs CA, Morris BJ, Sciascia AD, Edwards TB. Comparison of satisfied and dissatisfied patients 2 to 5 years after anatomic total shoulder arthroplasty.

J Shoulder Elbow Surg 2016;25:1128-32. https://doi.org/10.1016/j.jse.2015.12.001.
17. Khan A, Bunker TD, Kitson JB. Clinical and radiological follow-up of the Aequalis third-generation cemented total shoulder replacement: a minimum ten-year study. J Bone Joint Surg Br 2009;91:1594-600. https://doi.org/10.1302/0301-620X.91B12.22139.
18. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. J Bone Joint Surg Am Vol 2011;93:2249-54. https://doi.org/10.2106/JBJS.J.01994.
19. Kurowicki J, Rosas S, Yee LT, Levy JC. Participation in work and sport following reverse and total shoulder arthroplasty. Am J Orthop 2018;47:1-15. https://doi.org/10.12788/ajo.2018.0034.
20. Leschinger T, Raiss P, Loew M, Zeifang F. Predictors of medium-term clinical outcomes after total shoulder arthroplasty. Arch Orthop Trauma Surg 2017;137:187-93. https://doi.org/10.1007/s00402-016-2602-x.
21. Luedke C, Kissenberth MJ, Tolan SJ, Hawkins RJ, Tokish JM. Outcomes of anatomic total shoulder arthroplasty with B2 glenoids. JBJS Rev 2018;6:e7. https://doi.org/10.2106/JBJS.RVW.17.00112.
22. Mannava S, Horan MP, Frangiamore SJ, Hussain ZB, Fritz EM, Godin JA, et al. Return to recreational sporting activities following total shoulder arthroplasty. Orthop J Sport Med 2018;6. https://doi.org/10.1177/2325967118782672. 232596711878267.
23. Matsen FA, Russ SM, Vu PT, Hsu JE, Lucas RM, Comstock BA. What factors are Predictive of patient-reported outcomes? A prospective study of 337 shoulder arthroplasties. Clin Orthop Relat Res 2016;474:2496-510. https://doi.org/10.1007/s11999-016-4990-1.
24. Metzger CM, Farooq H, Merrell GA, Kaplan FTD, Greenberg JA, Crosby NE, et al. Efficacy of a single Image-Guided corticosteroid injection for glenohumeral arthritis. J Shoulder Elbow Surg 2021;30:1128-34. https://doi.org/10.1016/j.jse.2020.08.008.
25. Millett PJ, Horan MP, Pennock AT, Rios D. Comprehensive Arthroscopic Management (CAM) procedure: clinical results of a joint-preserving arthroscopic treatment for young, active patients with advanced shoulder osteoarthritis. Arthrosc - J Arthrosc Relat Surg 2013;29:440-8. https://doi.org/10.1016/j.arthro.2012.10.028.
26. Mitchell JJ, Horan MP, Greenspoon JA, Menge TJ, Tahal DS, Millett PJ. Survivorship and patient-reported outcomes after comprehensive arthroscopic management of glenohumeral osteoarthritis. Am J Sports Med 2016;44:3206-13. https://doi.org/10.1177/0363546516656372.
27. Mitchell JJ, Warner BT, Horan MP, Raynor MB, Menge TJ, Greenspoon JA, et al. Comprehensive arthroscopic management of glenohumeral osteoarthritis: preoperative factors Predictive of treatment failure. Am J Sports Med 2017;45:794-802. https://doi.org/10.1177/0363546516668823.
28. Papadonikolakis A, Neradilek MB, Matsen FA. Failure of the glenoid component in anatomic total shoulder arthroplasty. J Bone Joint Surg Am 2013;95:2205-12. https://doi.org/10.2106/JBJS.L.00552.
29. Petri M, Euler SA, Dornan GJ, Greenspoon JA, Horan MP, Katthagen JC, et al. Predictors for satisfaction after anatomic total shoulder arthroplasty for idiopathic glenohumeral osteoarthritis. Arch Orthop Trauma Surg 2016;136:755-62. https://doi.org/10.1007/s00402-016-2452-6.
30. Ponce BA, Ahluwalia RS, Mazzocca AD, Gobezie RG, Warner JJP, Millett PJ. Biomechanical and clinical evaluation of a novel lesser tuberosity repair technique in total shoulder arthroplasty. J Bone Joint Surg Am 2005;87(suppl_2):1-8. https://doi.org/10.2106/JBJS.E.00441.
31. R Development Core Team. R: a language and Environment for statistical Computing. R Found Stat Comput Vienna Austria 2016;0 {ISBN} 3-900051-07-0. https://doi.org/10.1038/sj.hdy.6800737.
32. Radnay CS, Setter KJ, Chambers L, Levine WN, Bigliani LU, Ahmad CS. Total shoulder replacement compared with humeral head replacement for the treatment of primary glenohumeral osteoarthritis: a systematic review. J Shoulder Elbow Surg 2007;16:396-402. https://doi.org/10.1016/j.jse.2006.10.017.
33. Raiss P, Aldinger PR, Kasten P, Rickert M, Loew M. Total shoulder replacement in young and middle-aged patients with glenohumeral osteoarthritis. J Bone Joint Surg Br 2008;90:764-9. https://doi.org/10.1302/0301-620X.90B6.20387.
34. Raiss P, Bruckner T, Rickert M, Walch G. Longitudinal observational study of total shoulder Replacements with cement. J Bone Jt Surg 2014;96:198-205. https://doi.org/10.2106/JBJS.M.00079.
35. Razmjou H, Stratford P, Kennedy D, Holtby R. Pattern of recovery following total shoulder arthroplasty and humeral head replacement. BMC Musculoskelet Disord 2014;15:306. https://doi.org/10.1186/1471-2474-15-306.
36. Styron JF, Higuera CA, Strnad G, Iannotti JP. Greater patient confidence yields greater functional outcomes after primary total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1263-7. https://doi.org/10.1016/j.jse.2015.04.018.
37. Swarup I, Henn CM, Nguyen JT, Dines DM, Craig EV, Warren RF, et al. Effect of pre-operative expectations on the outcomes following total shoulder arthroplasty. Bone Joint J 2017;99-B:1190-6. https://doi.org/10.1302/0301-620X.99B9.BJJ-2016-1263.R1.
38. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the Glenoid in primary glenohumeral osteoarthritis. J Arthroplasty 1999;14:756-60.
39. Walch G, Moraga C, Young A, Castellanos-Rosas J. Results of anatomic nonconstrained prosthesis in primary osteoarthritis with biconcave glenoid. J Shoulder Elbow Surg 2012;21:1526-33. https://doi.org/10.1016/j.jse.2011.11.030.
40. Wang J, Popchak A, Giugale J, Irrgang J, Lin A. Sports participation is an appropriate expectation for recreational Athletes undergoing shoulder arthroplasty. Orthop J Sport Med 2018;6:2325967118800666. https://doi.org/10.1177/2325967118800666.
41. Wilcox RB, Arslanian LE, Millett PJ. Rehabilitation following total shoulder arthroplasty. J Orthop Sport Phys Ther 2005;35:821-36. https://doi.org/10.2519/jospt.2005.35.12.821.
42. Wirth MA, Loredo R, Garcia G, Rockwood CA, Southworth C, Iannotti JP. Total shoulder arthroplasty with an all-polyethylene Pegged bone-Ingrowth glenoid component. J Bone Joint Surg Am Vol 2012;94:260-7. https://doi.org/10.2106/JBJS.J.01400.
43. Young A, Walch G, Boileau P, Favard L, Gohlke F, Loew M, et al. A multicentre study of the long-term results of using a flat-back polyethylene glenoid component in shoulder replacement for primary osteoarthritis. J Bone Jt Surg–Br Vol 2011;93-B:210-6. https://doi.org/10.1302/0301-620X.93B2.25086.
44. Zhang B, Thayaparan A, Horner N, Bedi A, Alolabi B, Khan M. Outcomes of hyaluronic acid injections for glenohumeral osteoarthritis: a systematic review and meta-analysis. J Shoulder Elbow Surg 2019;28:596-606. https://doi.org/10.1016/j.jse.2018.09.011.