Quantifying Success after Total Shoulder Arthroplasty: the Minimal Clinically Important Difference

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ABSTRACT

Background: Knowledge of the minimal clinically important difference [2] for different shoulder outcome metrics and range of motion following total shoulder arthroplasty can be useful to establish a minimum threshold of improvement that defines successful treatment. This study quantifies how MCID varies with different prosthesis types, patient age, gender, and length of follow-up after total shoulder arthroplasty.

Methods: 466 total shoulder arthroplasties (aTSA and rTSA) with two year minimum follow-up were performed by 13 shoulder surgeons. The MCID for the ASES, Constant, UCLA, SST, SPADI, global shoulder function, and VAS pain scores as well as active abduction, forward flexion, and external rotation were calculated for different prosthesis types and patient cohorts using an anchor-based method.

Results: The anchor-based MCID for ASES = 13.6 ± 2.3, Constant score = 5.7 ± 1.9, UCLA score = 8.7 ± 0.6, SST score = 1.5 ± 0.3, SPADI score = 20.6 ± 2.6, global shoulder function = 1.4 ± 0.3, pain VAS = 1.6 ± 0.3, active abduction = 7 ± 4°, active forward flexion = 12 ± 4°, and active external rotation = 3 ± 2°. Female gender and rTSA were both associated with lower MCID values as compared to males and aTSA patients.

Conclusion: The minimum improvement necessary for patients to achieve a result they believe is clinically meaningful following aTSA and rTSA is nominal and was achieved by at least 80%

of the patients. Future endeavors should investigate the influence of different anchor questions on the MCID calculation.

Level of evidence: II

Keywords: Minimal Clinically Important Difference, MCID, anatomic total shoulder arthroplasty, reverse total shoulder arthroplasty, shoulder arthroplasty, shoulder replacement

INTRODUCTION

Shoulder arthroplasty is a commonly accepted treatment for a variety of pathologies of the glenohumeral joint. A vast array of clinical and radiographic studies have demonstrated statistically significant improvements after both anatomic (aTSA) and reverse (rTSA) total shoulder arthroplasty. [(5-7, 9-11, 13, 21, 23, 24, 27, 28, 30, 33, 36, 37, 39)] Recently there has been interest in defining the minimal clinically important difference (MCID) after shoulder arthroplasty [(8, 32, 34)] to define the threshold of improvement that is clinically meaningful to a patient.

MCID was first defined by Jaeschke et al.[(14)] in 1989 to quantify the smallest difference in a clinical outcome measure that a patient would perceive as a beneficial and meaningful change by a given treatment. The MCID ideally avoids identification of small changes in outcome measures that appear to be meaningful solely due to statistical significance, which is dependent upon sample size and other study-power related variables[(18)]. Statistical significance can sometimes exist coincident with clinical irrelevance as judged by a patient.

There are three accepted methods for determining MCID: the distribution, Delphi, and anchor methods. The distribution method relies on statistical testing, typically utilizing a ratio of the standard deviation for a given metric. The Delphi method relies on repeated sampling of patients and experts to build MCID consensus. The anchor method evaluates clinical outcomes relative to a global question that can represent overall well-being or response to a surgical procedure or intervention.

Several different metrics are utilized to quantify outcomes after shoulder arthroplasty, including: the Simple Shoulder Test (SST), University of California - Los Angeles (UCLA), American Shoulder and Elbow Surgeon (ASES), Constant, Shoulder Pain and Disability Index (SPADI), and pain visual analog score (VAS) metrics[5,6,11,12,21,27-29].

With outcomes being tied to reimbursement, MCID thresholds are increasingly relevant and necessary to define the standard threshold for successful treatment, to ensure judicious allocation of finite economic resources relative to the performance of shoulder arthroplasty [1, 4, 26]. To this end, an improved understanding is needed for how MCID varies across different study cohorts and patient populations after total shoulder arthroplasty. For example, MCID may be influenced by variables beyond the control of the surgeon such as patient age, gender, and length of follow-up after surgery.

The purpose of this study is to quantify the MCID for the SST, UCLA, ASES, Constant, and SPADI tests after aTSA and rTSA. Additionally, we will quantify MCID for the pain VAS and global shoulder function scores. Finally, we will quantify the effect of prosthesis type, patient age, gender, and length of follow-up on the MCID for each of the aforementioned outcome metrics in order to establish a minimum threshold for successful treatment.

MATERIALS AND METHODS

This is a retrospective outcome study focused on patients treated with aTSA and rTSA that were prospectively enrolled in a multicenter database. Between February 2001 and February 2015 data was collected on 2,057 patients treated by 13 fellowship-trained orthopaedic surgeons using either primary aTSA or rTSA with a single platform shoulder system (Equinoxe; Exactech, Inc.; Gainesville, FL). IRB approval was obtained. Inclusion criteria included primary aTSA performed for osteoarthritis or rheumatoid arthritis as well as rTSA performed for cuff tear arthropathy or a combination of osteoarthritis and rotator cuff insufficiency. Patients with fracture diagnoses and revision cases were excluded. However, patients that were enrolled for a primary procedure and ultimately underwent revision for a complication were included in the analysis with the data recorded at the last visit prior to revision. Only patients with two years or more of clinical and radiographic follow-up were included.

The application of all inclusion and exclusion criteria resulted in 1,856 patients, consisting of 911 aTSA and 945 rTSA shoulders. The average age was 69.6 ± 8.8 years (range: 31-93). Gender analysis yielded 1098 females and 758 males. Average body mass index was 28.8 ± 5.9 (range: 17.0-48.1). Average follow-up was 44.9 ± 23.8 months (range: 24-157). Age, gender, BMI and length of follow-up differences between aTSA and rTSA patients is recorded in Table 1.

Patients were evaluated pre-operatively and at latest follow-up using the SST, UCLA, ASES, Constant, and SPADI metrics. Additionally, pain was recorded on a VAS from 0 to 10 in increments of 1. Similarly, a global shoulder function score was recorded from 0 to 10 in increments of 1. The global shoulder function was assessed by asking a patient to rate their shoulder on a scale from 0 to 10 with 10 being most functional. Active abduction, forward flexion, and external rotation were also recorded. Patient interrogation as well as range of motion and strength evaluation were performed by the procedural surgeon, a physical therapist, or research coordinator. Substantial effort was made to standardize the method of data collection and entry. Complications were recorded as well.

Radiographic analysis was conducted at latest follow-up using AP, axillary lateral, and scapular Y x-rays. Radiographs were evaluated for lucency around the humeral stem (aTSA and rTSA) and glenoid components (aTSA) according to the Gruen classification adapted to the humerus[(20)] and the Lazarus classification[(16)], respectively. Scapular notching (rTSA) was recorded according to the Nerot classification[(36)].

At latest follow-up, a global anchor question asked each patient to rate their shoulder as “worse, unchanged, better, or much better” relative to their pre-operative condition. This anchor question was modeled after the anchor question utilized by Tashjian et al.[32] who evaluated shoulder arthroplasty utilizing a response to treatment anchor question asking patients to rate their shoulder post-operatively as “poor”, “none”, “good” and “excellent”. We quantified the MCID as the minimal change in pre-to-post-operative outcome that resulted in a patient describing their treatment as "worse" or "unchanged" as compared to "better". As a result, patients who responded as being "much better" were excluded because their treatment exceeded this minimum threshold. The mean outcome metrics at latest follow-up for the unchanged group ("worse" + "unchanged") and the changed group ("better") were compared to the mean pre-operative metrics for each group to quantify the improvement associated with each group for a given metric. The MCID for each metric was then calculated as the difference in mean improvement between groups. MCID was also calculated for each metric using a distribution method of 50% of the standard deviation for the pre-to-post-operative improvement values. The cohort was also stratified according to 4 different variables: prosthesis type, patient age, gender, and follow-up duration (Table 2) to determine their effect on the anchor-based MCID. Finally, radiographic outcomes for humeral/glenoid lucency and scapular notching were analyzed along with the complication rate relative to anchor question.

A two-tailed, unpaired t-test identified statistical differences between pre-operative, post-operative, and pre-to-post-operative improvement values for all metrics. A two-tailed, unpaired t-test was also used to determine differences between the "worse", "unchanged", "better" and "much better" cohorts. for radiographic outcomes and complication rates. Statistical significance was set at $p<0.05$. 95% confidence intervals were used to compare differences in MCID for each metric and for each study cohort.

RESULTS

At latest follow-up and after analysis of 1,856 patients, both aTSA (Table 3) and rTSA (Table 4) patients were significantly better after surgery according to all metrics (Tables 3 and 4). Specifically, 90.4% of patients responded as being "much better" (n = 1390) or "better" (n = 288) after total shoulder arthroplasty, with only 9.6% of patients responding as being “unchanged” (n=113) or "worse" (n = 65) after treatment.

After exclusion of the "much better" patients, a total of 466 patients remained for analysis. The anchor-based MCID of the combined 466 patients (aTSA + rTSA) for the ASES score = 13.6 ± 2.3 [95% CI = 13.4 to 13.8], Constant score = 5.7 ± 1.9 [95% CI = 5.5 to 5.9], UCLA score = 8.7 ± 0.6 [95% CI = 8.6 to 8.8], SST score = 1.5 ± 0.3 [95% CI = 1.4 to 1.6], SPADI score = 20.6 ± 2.6 [95% CI = 20.4 to 20.8], global shoulder function = 1.4 ± 0.3 [95% CI = 1.37 to 1.43], pain VAS = 1.6 ± 0.3 [95% CI = 1.57 to 1.63], active abduction = 7 ± 4° [95% CI = 6° to 7°], active forward flexion = 12 ± 4° [95% CI = 11° to 12°], and active external rotation = 3 ± 2° [95% CI = 3° to 4°]. Generally, each of these MCID values were approximately 1/3 of the typical average improvement associated with each metric, as described in Tables 3 and 4 for aTSA and rTSA, respectively. By comparison, the 50% standard deviation distribution-based MCID for the ASES = 11.8, Constant score = 9.4, UCLA = 3.6, SST = 1.8, SPADI = 14.1, global shoulder function score = 1.4, VAS = 1.6, active abduction = 19°, active forward flexion = 21°, and active external rotation = 12°.

Applying these anchor-based MCID thresholds to the overall dataset of 1,856 patients demonstrated that 92.7% of patients achieved the MCID for the ASES score, 94.7% achieved the MCID for the Constant score, 90.8% achieved the MCID for the UCLA score, 92.0% achieved the MCID for the SST score, and 91.5% achieved the MCID for the SPADI score. Additionally, 86.8% of patients achieved the MCID for the global shoulder function score and 88.9% achieved the MCID for the pain VAS score. Finally, 82.4% of patients achieved the MCID for active abduction, 79.5% achieved the MCID for active forward flexion, and 81.5% achieved the MCID for active external rotation.

Tables 5, 6, 7, and 8 present the anchor-based MCID scores for each metric stratified according to prosthesis type, patient age, gender, and length of follow-up, respectively. Figure 1 graphically represents how ASES MCID varies for these four variables, as an example. To permit a more direct comparison of MCID between metrics, the SPADI, UCLA, and SST scores were normalized to a 100 point scale, like the ASES and Constant scores: ASES = 13.6 ± 2.3, Constant = 5.7 ± 1.9, UCLA = 24.9 ± 1.7, SST = 12.5 ± 2.5, and SPADI = 15.9 ± 2.0; doing so, demonstrated the UCLA had the largest relative MCID value whereas the Constant had the smallest.

Radiographic analysis determined the rate of humeral and glenoid radiolucent lines in the aTSA cohort. A significantly higher rate of humeral radiolucent lines was observed in the "unchanged"[15%] ($p = 0.0024$) and "better"[15.3%] ($p < 0.0001$) patients as compared to patients who responded as “much better”[4.2%]. Similarly, a significantly higher rate and grade of glenoid radiolucent lines was observed in the "worse"[64.0%] (rate p-value <0.0001; grade p-value <0.0001), "unchanged"[38.5%] (rate p-value = 0.0343; grade p-value = 0.0121), and "better"[35.1%] (rate p-value = 0.0153; grade p-value = 0.0049) patients as compared to patients who responded as "much better"[23.3%].

Radiographic analysis determined the rate of humeral radiolucent lines and scapular notching in the rTSA cohort. A significantly higher rate of humeral radiolucent lines was observed in the "unchanged"[14.0%] ($p = 0.0045$) patients as compared to patients who responded as “much better”[4.2%]. A significantly lower rate and grade of scapular notching was observed in the "unchanged"[7.1%] (rate p-value = 0.0314; grade p-value = 0.0303), "better"[5.9%] (rate p-value = 0.0022; grade p-value = 0.0170), and "much better"[8.4%] (rate p-value = 0.0050; grade p-value = 0.0014) patients as compared to patients who responded as "worse"[27.8%].

Out of the initial 1,856 patients analyzed, there were 128 complications yielding an overall complication rate of 6.9%. The complication rate was 33.8% in the “worse” group, 14.2% in the “unchanged group”, 10.4% in the “better group” and 4.3% in the “much better” group. The overall revision rate was 1.7% with a cohort revision rate of 15.4% in the “worse” group, 5.3% in the “unchanged” group, 3.1% in the “better” group and 0.5% in the “much better” group. The frequency distribution of complications included instability (3%), scapula and acromion fractures (10.4%), infection (11.9%), aseptic glenoid loosening (19.4%), aseptic humeral loosening (13.4%), combined aseptic glenoid and humeral loosening (1.4%), rotator cuff tear (11.9%), hematoma (1.5%), stiffness (6%), peri-prosthetic fracture (4.5%) and unexplained pain (16.4%). In the aTSA cohort, a significantly higher complication rate was observed in the "worse"[39.5%] (p-value <0.0001), "unchanged"[10.5%] (p-value = 0.0025), and "better"[10.2%] (p-value = 0.0001) patients as compared to patients who responded as "much better"[2.9%]. In the rTSA cohort, a significantly higher complication rate was observed in the "worse"[25.9%] (p-value <0.0001), "unchanged"[17.9%] (p-value = 0.0004), and "better"[10.6%] (p-value = 0.0254) patients as compared to patients who responded as "much better"[5.7%].

DISCUSSION

Despite the prevalence of MCID investigations after spinal fusion and lower extremity arthroplasty[2, 3, 12, 17, 19, 25, 35] as well as for the non-operative and operative treatment of rotator cuff disease[15, 31], few studies have examined the MCID for common outcome metrics after total shoulder arthroplasty.[32, 34, 38] Based on our investigation of 466 patients with 2 year minimum follow-up, our calculations of MCID demonstrate that a modest change in the ASES, Constant, UCLA, SST, SPADI, global shoulder function, and pain VAS scores and also the 3 active ROM measurements represent a meaningful clinical improvement for patients undergoing total shoulder arthroplasty.

Tashjian et al.[32] recently analyzed a cohort of 326 patients consisting of 198 aTSA, 124 rTSA, and 4 hemiarthroplasties with 2 years minimum follow-up. After stratifying the cohort using a similar anchor-based question, 133 patients remained for analysis. From this cohort they determined the MCID for ASES = 20.9, SST = 2.4, and VAS = 1.4. While we report a very similar MCID for VAS (1.6 ± 0.3), we found the MCID for the ASES (13.6 ± 2.3) and SST scores (1.5 ± 0.3) to be substantially lower. Similarly, Torrens et al.[34] quantified the MCID for the Constant score from a cohort of 60 rTSA patients with 1 year minimum follow-up also using an anchor-based method. They reported a MCID for Constant of 8, which was slightly larger than what we found (5.7 ± 1.9). These differences in MCID between these studies are likely due to our larger sample size, different distribution of aTSA/rTSA prostheses, different distributions of male/female patients, and slightly greater improvement scores, as compared to those reported by both Tashjian et al.[32] and Torrens et al.[34].

Werner et al.[38] quantified MCID for the ASES score in a cohort of 490 total shoulder arthroplasty patients, of which 304 had 2 years minimum follow-up. This combined aTSA and rTSA cohort of patients were stratified with an anchor question into two groups: "no change" and "minimum improvement", leaving 67 patients available for analysis. From this group, they calculated the MCID for ASES to be 13.5 ± 4.5, which is in close agreement with our findings for the combined aTSA and rTSA cohort (13.6 ± 2.3). Werner et al. also analyzed the MCID for the ASES score using 2 different anchor questions: "satisfaction pertaining to work" and "satisfaction for activities", separately, and demonstrated the ASES MCID varied considerably for work satisfaction (6.3 ± 4.4) and activity satisfaction (9.1 ± 4.0), relative to the aforementioned overall satisfaction score (13.5 ± 4.5). [38] Such variances demonstrate how different anchor questions can precipitously influence the MCID calculation.

As we observed with the MCID for each outcome metric, the MCID for active abduction, forward flexion, and external rotation demonstrated that very modest improvements in range of motion after total shoulder arthroplasty result in meaningful clinical improvements for patients. These results are corroborated by Torrens et al.[34] in their study of 60 rTSA patients, who reported that only very small improvements in active external rotation (MCID = 2) were necessary for patient perception of a clinically meaningful improvement. We found the MCID for active external rotation in rTSA patients to be -5.3 ± 3.1°, suggesting that restoration of function in that patient group is subordinate to other factors (such as pain relief, joint stability, and a low complication rate), in order for the procedure to be deemed satisfactory by the patient.

Our stratification of MCID results according to prosthesis type, patient age, gender, and length of follow-up revealed some interesting findings. As described in Table 6, aTSA patients required a larger MCID compared to rTSA regardless of outcome metric or motion measurement. We hypothesize that this may be due to underlying differences in the cohorts regarding disease diagnosis and distribution of age and/or gender, all of which may influence patient expectations. As described in Table 1, rTSA patients had a significantly higher percentage of female patients as compared to the aTSA group ($p < 0.0001$); rTSA patients were also significantly older ($p < 0.0001$). As described in Table 8, analysis of gender influence on MCID revealed that females required lower MCID for all outcome metrics and motion measurements, except the SPADI score, which were similar. Prosthesis type and gender are variables that coexist and have a synchronous effect on MCID. Werner et al[38] reported the MCID for ASES of aTSA patients to be 16.1 ± 5.4 and rTSA patients to be 8.4 ± 2.9; this 7.7 point differential is similar to our findings of a 6.7 point differential for the ASES MCID (Figure 1 and Table 6). Werner et al. reported that the differential was not statistically significant[38]; however, given the magnitude of the mean difference, the lack of statistical significance is likely due to a study power issue resulting from the small sample size of rTSA patients (only 17 of 67). Conversely, Tashjian et al.[32] did not find any correlation between implant type (aTSA, rTSA) and MCID for the pain VAS, ASES, or SST scores and they also reported that female gender statistically correlated with higher pain VAS and ASES scores. These contradictory findings may be due to the use of different anchor questions or due to other more complex factors such as variable frequencies of disease diagnosis or patient factors that were beyond the scope of understanding of our study.

While prosthesis type, patient age, gender, and length of follow-up appeared to variably impact the MCID for each of the outcome metrics studied, the UCLA score consistently demonstrated the least variability. Thus, the UCLA metric may be most immune to influence by external patient factors making it ideal for use in heterogeneous populations and the most appropriate for MCID comparison between different studies. Further evaluation using other heterogeneous populations is necessary to corroborate this finding.

Ours is the first study to simultaneously evaluate the MCID of seven commonly used metrics to quantify outcomes after total shoulder arthroplasty and also 3 active motion measurements. Five of these metrics (ASES, Constant, UCLA, SPADI, and SST) were compared on a normalized 100 point scale to demonstrate vast differences in MCID values, with the UCLA associated with the largest relative MCID and the Constant the smallest. Such differences suggest that each metrics emphasis of pain, function, and range of motion are disparate enough that they cannot be conflated. Therefore, care should be made when comparing studies utilizing different metrics.

This study examined the incidence of humeral and glenoid radiolucencies, scapular notching, and complications relative to a patient-reported satisfaction anchor question. Higher rates of humeral and glenoid lucency after aTSA corresponded to a worse patient outcome rating. Similarly, higher rates of both humeral lucency and scapular notching after rTSA corresponded to a worse patient outcome rating. This finding is consistent with the negative impact of scapular notching on rTSA clinical outcomes as previously reported by Simovitch et al.[29] and Mollon et al.[22] Furthermore, higher complication rates after both aTSA and rTSA corresponded to worse patient outcome ratings.

There are several limitations to this study. Calculation of MCID is sensitive to the anchor question. Our anchor question was not validated but it was similar to those utilized by previous MCID studies on shoulder arthroplasty.[32] The validity of our calculated MCID values using the anchor-based method is strengthened by its similarity to our calculated MCID using the distribution method, particularly as it relates to the 7 shoulder outcome metrics. Additionally, this study utilized data from a prospectively collected database of one particular shoulder prosthesis, which is subject to enrollment bias. However, the use of such a database has several distinct advantages for this study. Primarily, the database provided a substantially larger cohort of patients than any previous MCID analysis of the shoulder. Additionally, the database enrolled patients of thirteen different shoulder surgeons from academic and community practice, increasing the likelihood that the MCID derived from this data is applicable across shoulder arthroplasty patients in general, and not just those undergoing surgery in a particular setting. Finally, the average follow-up of this study was only 45 months, with only 19% of the 466 patient cohort having >72 months follow-up; additional and longer term follow-up is necessary to confirm these findings and better understand how MCID changes with follow-up duration.

CONCLUSION

Based on quantifying the MCID of multiple metrics, we demonstrated that a modest change in each of these outcome measures represents a clinically meaningful difference to patients after total shoulder arthroplasty. Female gender and rTSA were both associated with lower MCID values as compared to males and aTSA patients. Furthermore, higher rates of prosthetic radiolucencies, scapular notching, and complications corresponded to worse outcomes, as determined by the anchor question. Future efforts should evaluate the impact of different anchor questions on the MCID calculations and establish a consensus standard threshold for success after total shoulder arthroplasty.

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Figure Legend

Figure 1. Graphical demonstration of MCID stratified according to time of follow-up, age, gender, and prosthesis type for ASES score.

Table Legends

Table 1. Comparison of demographics of the rTSA & aTSA cohort

Table 2. Variables used to stratify patients to examine effect on MCID.

Table 3. Clinical outcome results of aTSA patients at latest follow-up (n=911)

Table 4. Clinical outcome results of rTSA patients at latest follow-up (n=945)

Table 5. MCID stratified according to prosthesis type.

Table 6. MCID stratified according to age at time of surgery.

Table 7. MCID stratified according to gender.

Table 8. MCID stratified according to length of follow-up.

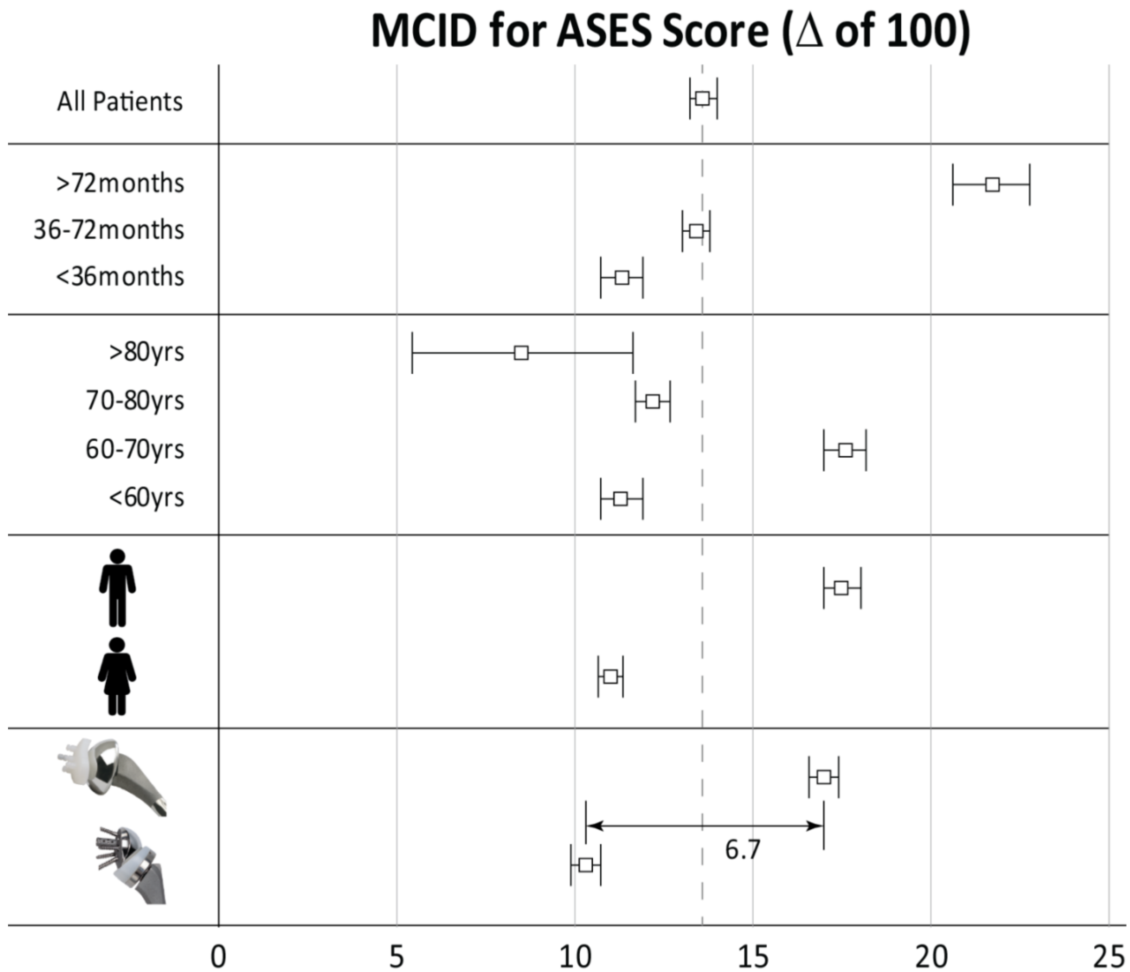

Figure 1. Graphical demonstration of MCID stratified according to time of follow-up, age, gender, and prosthesis type for ASES score.

Demographics	aTSA Cohort	rTSA Cohort	P Value
Gender	488F / 423M	610F / 335M	<0.0001
Age (years)	66.5 ± 9.1	72.5 ± 7.5	<0.0001
BMI	29.5 ± 6.1	28.1 ± 5.6	<0.0001
Follow-up (months)	49.7 ± 27.5	40.2 ± 18.6	<0.0001

Table 1. Comparison of demographics of the rTSA & aTSA cohort

Prosthesis Type	aTSA (n=911)	rTSA (n=945)		
Gender	Female (n=1098)	Male (n=758)		
Age (years)	<60 (n=236)	60-70 (n=624)	70-80 (n=769)	>80 (n=225)
Follow up (months)	<36 (n=839)	36-72 (n=763)	>72 (n=243)	

Table 2. Variables used to stratify patients to examine effect on MCID.

Outcome Metric	Pre-op	Post-op	Improvement	P Value (pre vs post)
ASES	36.5 ± 16.9	84.1 ± 19.3	49.0 ± 22.6	**<0.0001**
Constant	37.7 ± 13.2	71.3 ± 15.2	34.5 ± 16.2	**<0.0001**
UCLA	14.0 ± 4.2	30.2 ± 5.8	16.7 ± 6.4	**<0.0001**
SST	3.8 ± 2.9	10.4 ± 2.4	6.7 ± 3.2	**<0.0001**
SPADI	83.6 ± 23.1	18.5 ± 24.1	65.0 ± 29.0	**<0.0001**
VAS	6.3 ± 2.2	1.4 ± 2.2	5.1 ± 2.8	**<0.0001**
Global Shoulder Function	4.0 ± 2.0	8.2 ± 2.1	4.4 ± 2.7	**<0.0001**
Active Abduction (°)	81.6 ± 27.8	124.1 ± 33.1	41.9 ± 39.0	**<0.0001**
Active Forward Flexion (°)	97.1 ± 30.8	142.8 ± 31.7	45.6 ± 39.0	**<0.0001**
Active External Rotation (°)	16.4 ± 20.4	48.5 ± 20.3	32.2 ± 23.1	**<0.0001**

Table 3. Clinical outcome results of aTSA patients at latest follow-up (n=911)

Outcome Metric	Pre-op	Post-op	Improvement	P Value (pre vs post)
ASES	36.6 ± 15.7	82.9 ± 18.3	46.5 ± 20.6	**<0.0001**
Constant	34.1 ± 13.7	69.7 ± 14.1	35.8 ± 16.7	**<0.0001**
UCLA	13.0 ± 4.2	29.7 ± 5.1	16.7 ± 5.7	**<0.0001**
SST	3.4 ± 2.7	9.9 ± 2.6	6.6 ± 3.3	**<0.0001**
SPADI	83.3 ± 22.1	21.1 ± 23.9	61.2 ± 28.0	**<0.0001**
VAS	6.0 ± 2.2	1.2 ± 2.1	4.8 ± 2.6	**<0.0001**
Global Shoulder Function	3.6 ± 2.0	8.0 ± 2.0	4.4 ± 2.6	**<0.0001**
Active Abduction (°)	69.6 ± 34.5	112.6 ± 29.2	43.0 ± 38.7	**<0.0001**
Active Forward Flexion (°)	85.6 ± 39.4	136.8 ± 28.1	51.3 ± 43.6	**<0.0001**
Active External Rotation (°)	16.0 ± 22.3	35.1 ± 17.8	18.9 ± 24.5	**<0.0001**

Table 4. Clinical outcome results of rTSA patients at latest follow-up (n=945)

Patient Satisfaction	% of aTSA Cohort	% of rTSA Cohort	% of Female Cohort	% of Male Cohort	% <60yro Cohort	% 60-70yro Cohort	70-80 yro Cohort	>80yro Cohort	<36 month follow-up cohort	36-72 month follow-up cohort	>72 month follow-up cohort
Worse	38 of 911 (4.2%)	27 of 945 (2.9%)	40 of 1097 (3.6%)	25 of 754 (3.3%)	14 of 236 (5.9%)	25 of 624 (4.0%)	23 of 769 (3.0%)	3 of 225 (1.3%)	25 of 839 (3.0%)	26 of 763 (3.4%)	14 of 243 (5.8%)
Unchanged	57 of 911 (6.3%)	56 of 945 (5.9%)	59 of 1097 (5.4%)	52 of 754 (6.9%)	26 of 236 (11.0%)	35 of 624 (5.6%)	44 of 769 (5.7%)	8 of 225 (3.6%)	45 of 839 (5.4%)	45 of 763 (5.9%)	22 of 243 (9.1%)
Better	127 of 911 (13.9%)	161 of 945 (17.0%)	185 of 1097 (16.9%)	102 of 754 (13.5%)	48 of 236 (20.3%)	88 of 624 (14.1%)	122 of 769 (15.9%)	29 of 225 (12.9%)	113 of 839 (13.5%)	121 of 763 (15.9%)	53 of 243 (21.8%)
Much Better	689 of 911 (75.6%)	701 of 945 (74.2%)	813 of 1097 (74.1%)	575 of 754 (76.3%)	148 of 236 (62.7%)	476 of 624 (76.3%)	580 of 769 (75.4%)	185 of 225 (82.2%)	656 of 839 (78.2%)	571 of 763 (74.8%)	154 of 243 (63.4%)

Table 5. Distribution of the anchor question response for each cohort

Outcome Metric	MCID rTSA [95% CI]	MCID aTSA [95% CI]
ASES	10.3 ± 3.3 [9.9 to 10.7]	17.0 ± 3.2 [16.6 to 17.4]
Constant	-0.3 ± 2.8 [-0.7 to 0.1]	12.8 ± 2.5 [12.5 to 13.1]
UCLA	7.0 ± 0.8 [6.9 to 7.1]	10.5 ± 0.8 [10.4 to 10.6]
SST	1.4 ± 0.5 [1.3 to 1.5]	1.8 ± 0.4 [1.7 to 1.9]
SPADI	20.0 ± 3.9 [19.5 to 20.5]	21.3 ± 3.5 [20.8 to 21.8]
VAS	1.4 ± 0.4 [1.3 to 1.5]	2.7 ± 0.4 [2.6 to 2.8]
Global Shoulder Function	1.0 ± 0.4 [0.9 to 1.1]	1.7 ± 0.4 [1.6 to 1.8]
Active Abduction (°)	-1.9 ± 4.9 [-2.5 to -1.3]	13.9 ± 5.3 [13.2 to 14.6]
Active Forward Flexion (°)	-2.9 ± 5.5 [-3.6 to -2.2]	23.1 ± 5.8 [22.3 to 23.9]
Active External Rotation (°)	-5.3 ± 3.1 [-5.7 to -4.9]	14.5 ± 3.2 [14.1 to 14.9]

Table 6. MCID stratified according to prosthesis type.

Outcome Metric	MCID < 60 yo [95% CI]	MCID 60-70 yo [95% CI]	MCID 70-80 yo [95% CI]	MCID > 80 yo [95% CI]
ASES	11.3 ± 4.9 [10.3 to 12.3]	17.6 ± 3.5 [17.0 to 18.2]	12.2 ± 3.8 [11.7 to 12.7]	8.5 ± 9.9 [5.4 to 11.6]
Constant	8.1 ± 4.0 [7.3 to 8.9]	8.9 ± 2.8 [8.5 to 9.4]	3.4 ± 3.4 [2.9 to 3.9]	-7.7 ± 7.0 [-9.9 to -5.5]
UCLA	9.7 ± 1.3 [9.4 to 10.0]	9.4 ± 0.9 [9.3 to 9.5]	7.7 ± 0.9 [7.6 to 7.8]	7.2 ± 2.4 [6.5 to 7.9]
SST	2.5 ± 0.8 [2.3 to 2.7]	1.9 ± 0.6 [1.8 to 2.0]	0.6 ± 0.6 [0.5 to 0.7]	1.7 ± 1.4 [1.3 to 2.1]
SPADI	15.3 ± 5.9 [14.1 to 16.5]	25.6 ± 4.1 [24.9 to 26.3]	16.7 ± 4.3 [16.1 to 17.3]	36.7 ± 7.7 [34.3 to 39.1]
VAS	1.2 ± 0.7 [1.1 to 1.4]	2.3 ± 0.5 [2.2 to 2.4]	1.5 ± 0.5 [1.4 to 1.6]	0.3 ± 1.3 [-0.1 to 0.7]
GlobalShoulder Function	2.1 ± 0.7 [2.0 to 2.3]	1.0 ± 0.4 [0.9 to 1.1]	1.1 ± 0.4 [1.0 to 1.2]	2.3 ± 1.1 [2.0 to 2.6]
Active Abduction (°)	-6.9 ± 8.5 [-8.7 to -5.1]	7.2 ± 5.9 [6.3 to 8.2]	11.3 ± 6.0 [10.4 to 12.2]	6.0 ± 11.0 [2.6 to 9.4]
Active Forward Flexion (°)	2.6 ± 8.5 [0.8 to 4.4]	17.2 ± 6.8 [16.1 to 18.3]	11.3 ± 7.0 [10.3 to 12.3]	5.2 ± 10.1 [2.1 to 8.3]
Active External Rotation (°)	7.9 ± 5.0 [6.9 to 8.9]	6.0 ± 3.7 [5.4 to 6.6]	0.9 ± 3.5 [0.4 to 1.4]	-5.5 ± 8.7 [-8.2 to -2.8]

Table 7. MCID stratified according to age at time of surgery.

Outcome Metric	MCID Female [95% CI]	MCID Male [95% CI]
ASES	11.0 ± 3.0 [10.7 to 11.4]	17.5 ± 3.5 [17.0 to 18.0]
Constant	1.7 ± 2.5 [1.4 to 2.0]	10.5 ± 3.0 [10.1 to 10.9]
UCLA	7.4 ± 0.7 [7.3 to 7.5]	10.2 ± 0.9 [10.1 to 10.3]
SST	1.2 ± 0.5 [1.1 to 1.3]	1.8 ± 0.5 [1.7 to 1.9]
SPADI	22.1 ± 3.3 [21.7 to 22.5]	20.6 ± 4.3 [20.0 to 21.2]
VAS	1.2 ± 0.4 [1.1 to 1.3]	2.2 ± 0.4 [2.1 to 2.3]
Global Shoulder Function	1.2 ± 0.3 [1.1 to 1.3]	1.3 ± 0.4 [1.2 to 1.4]
Active Abduction (°)	5.0 ± 4.9 [4.4 to 5.6]	7.3 ± 5.4 [6.5 to 8.1]
Active Forward Flexion (°)	8.7 ± 5.3 [8.1 to 9.3]	13.9 ± 6.5 [13.0 to 14.9]
Active External Rotation (°)	0.8 ± 3.2 [0.4 to 1.2]	6.1 ± 3.1 [5.7 to 6.6]

Table 8. MCID stratified according to gender.

Outcome Metric	MCID <36 months [95% CI]	MCID 36-72 months [95% CI]	MCID >72 months [95% CI]
ASES	11.3 ± 4.0 [10.7 to 11.9]	13.4 ± 3.1 [13.0 to 13.8]	21.7 ± 5.1 [20.6 to 22.8]
Constant	4.0 ± 3.6 [3.5 to 4.5]	6.6 ± 2.4 [6.3 to 6.9]	11.6 ± 3.5 [10.9 to 12.3]
UCLA	8.5 ± 1.0 [8.4 to 8.6]	9.3 ± 0.8 [9.2 to 9.4]	9.7 ± 1.2 [9.5 to 10.0]
SST	1.2 ± 0.6 [1.1 to 1.3]	1.2 ± 0.4 [1.1 to 1.3]	3.3 ± 0.7 [3.2 to 3.5]
SPADI	25.7 ± 4.4 [25.1 to 26.3]	9.9 ± 3.9 [9.4 to 10.5]	34.9 ± 5.5 [33.8 to 36.0]
VAS	1.7 ± 0.5 [1.6 to 1.8]	1.2 ± 0.4 [1.1 to 1.3]	2.5 ± 0.7 [2.4 to 2.7]
Global Shoulder Function	1.4 ± 0.5 [1.3 to 1.5]	1.4 ± 0.4 [1.3 to 1.5]	1.5 ± 0.5 [1.4 to 1.6]
Active Abduction (°)	5.7 ± 6.7 [4.7 to 6.7]	2.5 ± 5.1 [1.8 to 3.2]	18.2 ± 6.9 [16.8 to 19.6]
Active Forward Flexion (°)	11.7 ± 6.9 [10.7 to 12.7]	8.7 ± 6.3 [7.8 to 9.6]	19.7 ± 8.0 [18.0 to 21.4]
Active External Rotation (°)	4.9 ± 3.8 [4.4 to 5.5]	-0.7 ± 3.0 [-1.1 to -0.3]	7.3 ± 6.0 [6.1 to 8.5]

Table 9. MCID stratified according to length of follow-up.

aTSA Patient Satisfaction	Humeral Radio Line Rate	Glenoid Radio Line Rate	Complication Rate
Worse	11.1%	64.0%	39.5%
Unchanged	15.0%	38.5%	10.5%
Better	15.3%	35.1%	10.2%
Much Better	4.2%	23.3%	2.9%

Table 10. Radiographic outcomes and complication rates after aTSA.

rTSA Patient Satisfaction	Humeral Radio Line Rate	Scapular Notching Rate	Complication Rate
Worse	5.6%	27.8%	25.9%
Unchanged	14.0%	7.1%	17.9%
Better	5.0%	5.9%	10.6%
Much Better	4.2%	8.4%	5.7%

Table 11. Radiographic outcomes and complication rates after rTSA.