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# Cost-effectiveness analyses in shoulder arthroplasty: a critical review using the Quality of Health Economic Studies (QHES) instrument

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**Hypothesis:** The purpose of this study was to perform a systematic review to identify cost-analysis studies pertaining to shoulder arthroplasty, provide a comprehensive review of published studies, and critically evaluate the quality of the available literature using the Quality of Health Economic Studies (QHES) instrument.

**Methods:** A systematic review of the literature was performed to identify cost analyses examining shoulder arthroplasty. The inclusion criteria included studies pertaining to either shoulder hemiarthroplasty (HA), total shoulder arthroplasty (TSA), or reverse TSA. Articles were excluded based on the following: nonoperative studies, nonclinical studies, studies not based in the United States, and studies in which no cost analysis was performed. The quality of studies was assessed using the QHES instrument. One-sided Fisher exact testing was performed to identify predictors of both low-quality (ie, QHES score $<$ 25th percentile) and high-quality (ie, QHES score $>$ 75th percentile) cost analyses based on items within the QHES checklist.

**Results:** Of the 196 studies screened, 9 were included. Seven studies conducted cost analyses comparing reverse TSA vs. arthroscopic rotator cuff repair, HA, or total hip arthroplasty, and 2 studies examined TSA vs. HA for primary glenohumeral arthritis. The average QHES score among all studies was 86.22 $\pm$ 13.39 points. Failure to include an annual cost discounting rate was associated with a low-quality QHES score ($P = .03$). In addition, including a discussion of the magnitude and direction of potential biases was associated with a high-quality score ($P = .03$).

**Conclusions:** Shoulder arthroplasty is a cost-effective procedure when used to treat a multitude of shoulder pathologies. The overall quality of cost analysis in shoulder arthroplasty is relatively good, with an average QHES score of 86.22 points. Studies failing to include an annual cost discounting rate are more likely to score below the 25th percentile, whereas those including a discussion of the magnitude and direction of potential biases are more likely to achieve a score in excess of the 75th percentile.

**Level of evidence:** Level IV; Systematic Review; Economic Analysis



**Keywords:** Cost; CUA; CEA; cost analysis; arthroplasty; total shoulder arthroplasty; TSA; systematic review

Orthopedic surgical interventions represent 4 of the 5 most common surgical procedures in the United States, including hip and knee arthroplasty, laminectomy, and spinal fusion.[12] In 2011 alone, it was estimated that the

Institutional review board approval was not required for this systematic review.

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costs associated with musculoskeletal disease averaged $763.3 billion, culminating in around 5.7% of the US gross domestic product.[42] The topic of health care economics, particularly with respect to utilization trends and measuring value,[26] has become increasingly relevant among health care analysts.[4] Orthopedic surgical care of shoulder conditions represents an area of particular growth and development,[13,22] with shoulder replacement surgery paralleling annual growth rates seen in total knee arthroplasty[10] and projections estimating a 9-fold increase by 2030.[34]

As orthopedic care in the United States moves toward a value-based approach,[26] economic evaluations in the form of cost analyses as tools to identify interventions that provide the best outcomes at the lowest cost (ie, have the best value) continue to gain importance. This becomes especially important when determining appropriate allocation of monetary resources within a fixed health care budget. In response to this trend, there has been an increasing emphasis on publication of evidence-based, high-level cost-effectiveness analyses, especially within the field of orthopedic surgery.[4-6,20,26] Thought leaders within the field have pushed to better understand value and its application to orthopedic surgery.[16,26] Specifically, the American Shoulder and Elbow Surgeons has recently developed a committee dedicated to incorporating value-based principles in the treatment of shoulder disorders.[3]

Recently, the field of orthopedic surgery has been particularly active with respect to evaluating the quality of cost analysis within many subspecialty domains.[5,6,27,29,30] With the increasing number of cost analyses being published, there is an increased need to stratify economic studies regarding their quality of analysis and level of detail. Instruments such as the Quality of Health Economic Studies (QHES) checklist[31] and the US Panel on Cost-Effectiveness in Health and Medicine checklist[36,44] have been developed to identify important features of high-quality economic studies.[24] The QHES instrument is a validated grading system, designed by 8 health economics experts, used to critically evaluate the quality of economic studies.[8] This questionnaire has been used across all fields of health care and recently within the orthopedic realm, including hip and knee arthroplasty, trauma, sports medicine, and spine care.[8,25,27,30] It consists of 16 binary criteria stated as yes or no questions pertaining to a study's methodology, with each question weighted differently such that overall scores range from 0 to 100 points.[31] A standard metric for rating QHES scores in the literature is lacking; however, previous studies within orthopedics have used a cutoff score of 85 points to define studies as high quality.[25,27,30]

Few studies critically evaluating the economic-analysis literature in shoulder surgery are available.[3,19,40] Furthermore, to our knowledge, no studies exist collectively focusing solely on the cost-analysis literature in shoulder arthroplasty. Accordingly, the purpose of this study was to provide a comprehensive review of published United States–based cost analyses pertaining to shoulder arthroplasty. Secondarily, we aimed to evaluate the overall quality of available studies using a validated instrument and identify factors predictive of the achievement of low- and high-quality scores. We hypothesized that there would be a paucity of published economic analyses pertaining to shoulder arthroplasty and the overall quality of studies based on the QHES checklist would be poor.

## Methods

### Article identification and screening process

A systematic search strategy was applied using the MEDLINE database. Data were extracted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. An a priori search algorithm with the following search terms was used: (''Shoulder'' OR ''Shoulder Surgery'') AND (''Glenohumeral osteoarthritis'' OR ''Shoulder Arthroplasty'' OR ''Total Shoulder Arthroplasty'' OR ''Reverse Total Shoulder Arthroplasty'' OR ''Hemiarthroplasty'') AND (''Cost'' OR ''Cost Analysis'' OR ''Cost Utility'' OR ''Cost effectiveness'' OR ''Cost minimization'' OR ''Cost benefit'' OR ''Economics''). A total of 197 articles were identified prior to title and abstract screening. The inclusion criteria were as follows: (1) index procedure(s) in studies consistent with at least 1 form of shoulder arthroplasty (ie, hemiarthroplasty [HA], anatomic total shoulder arthroplasty [TSA], or reverse total shoulder arthroplasty [rTSA]); (2) a cost analysis involving either cost-effectiveness analysis (CEA), cost-utility analysis (CUA), or cost-benefit analysis; (3) studies based in the United States; (4) clinical studies; and (5) economic modeling performed using real data or data from economic models. Studies pertaining to orthopedic subspecialties outside of shoulder arthroplasty were excluded from the analysis. Non–United States–based studies, review articles, case reports, nonoperative and nonclinical studies, cost-identification (-minimization) studies, and studies that did not perform a cost analysis were excluded. Of the major types of cost analyses, cost minimization is considered the most basic and inferior, with experts suggesting against its use within economic analyses.[7] The various forms of CEA examined in this review are summarized in Table I.[17,27,43]

### Search results and article inclusion

Our search identified 197 total studies. Studies were initially included or excluded based on a review of the study title and abstract. If there was any ambiguity regarding inclusionary status, the article was retrieved for further full-text review. In all, after review of 197 initial studies, we identified 9 studies for inclusion (Fig. 1). A manual search of each included study's references was performed and did not identify any additional studies.

### Quality scoring

The QHES instrument was used to grade each included study. This instrument is composed of 16 questions with binary yes or no answers. Each question is weighted differently using point values ranging from 1 to 9 such that total scores range from 0 to 100 points.

Answers of yes received the full allotted points per question, whereas answers of no received 0 points. Two authors (W.M.C. and A.B.) independently graded each included study using the QHES instrument (Supplementary Appendix S1). Any discrepancy in scoring was discussed between these 2 authors until a consensus agreement on the final score was reached. Each individually scored criterion was them summated to achieve a final score per cost analysis out of 100 points. To remain consistent with previous methods for reporting author-based quality scoring, we present the quality of studies as a conglomerate score as opposed to the score of each study.[6,29,30]

### Characteristics associated with high-quality evidence

The distribution of scores was assessed using Fisher exact testing to statistically test for the achievement of scores in a specific percentile range. A low-quality score was deemed below the 25th percentile (<82 points), whereas a high-quality score was deemed above the 75th percentile (>94 points). An analysis to evaluate factors associated with achieving both low- and high-quality QHES scores was conducted, based on both scientific and general factors previously reported within high-quality cost literature.[30,32,33,38,39] Scientific factors of interest were inclusive of the following: use of randomized cohort data, cohort size >100 patients, use of sensitivity analysis, use of societal perspective for analysis, application of a cost discounting rate, application of an incremental analysis, and use of Markov modeling for analysis. Nonscientific factors included disclosure of funding.

### Statistical methods

Bivariate analysis consisting of 2-sided Fisher exact testing was performed to test for associations between the prespecified factors and the achievement of either a high-quality score (>94 points) or low-quality score (<82 points). $P < .05$ was considered statistically significant. RStudio software (version 1.0.143; R Foundation for Statistical Computing, Vienna, Austria) was used for all relevant statistical analyses.

## Results

### Overview of included studies

A total of 9 studies were identified and included after application of the inclusion and exclusion criteria as outlined in Figure 1. Of these studies, 5 focused on rotator cuff pathology, 2 focused on glenohumeral osteoarthritis, 1 focused on proximal humeral fractures, and 1 compared

**Table I** Summary of cost-analysis terminology

CEA
- CEA is used to compare costs of certain health outcome measures obtained through different interventions. CEA uses objective health outcomes (eg, fracture union rate) and can be performed across a wide variety of scenarios as long as the outcomes measured remain similar.
- CEA can report the added cost and/or added health benefit in the form of an ICER, which represents the degree of health benefited per incremental cost consumed.
- A major advantage of CEA is avoidance of subjective outcome measures; thus, patient preferences are not considered (major difference from CUA).
- Disadvantages include the lack of ability to compare interventions with different outcomes.

CUA
- CUA is similar to CEA; however, outcomes are standardized into patient-centric subjective health utility measures (ie, QALYs), allowing comparison of interventions with different outcomes to be measured across all fields of medicine.
- Like the ICER, an incremental cost-utility ratio can be measured and applied through CUA.
- CUA remains the gold standard for reporting results of economic analyses[19,20,42] and is becoming more widely used across orthopedic surgery.[8,17]

Cost-benefit analysis
- Cost-benefit analysis is different from CEA and CUA in that this type of analysis evaluates interventions from a purely financial standpoint.
- Outcomes of interventions are reported in monetary benefits, such as an individual's or consumer's willingness to pay to attain a certain health state.

Cost-identification (-minimization) analysis
- Cost-identification (-minimization) analysis tabulates and compares costs associated with certain interventions to identify the least expensive option.
- One of the major disadvantages of this type of analysis is that it requires equal outcomes between comparative interventions. Thus, by definition, outcomes are not valued in this type of analysis.

*CEA*, cost-effectiveness analysis; *ICER*, incremental cost-effectiveness ratio; *CUA*, cost-utility analysis; *QALY*, quality-adjusted life-year.

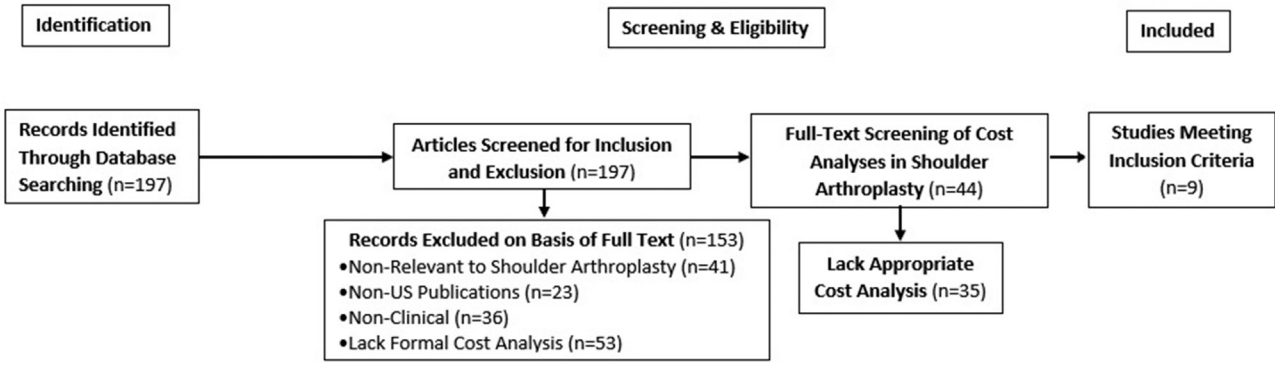


**Figure 1** Inclusion and exclusion diagram. *US*, United States.

shoulder arthroplasty vs. hip arthroplasty. Of the 9 included articles, 7 (78%) were published between 2013 and 2017. Table II presents a summary of the economic findings of all 9 studies.

## Shoulder arthroplasty for rotator cuff tears with or without presence of cuff tear arthropathy

A majority of the cost-effectiveness literature within shoulder arthroplasty focuses on the treatment of massive rotator cuff tears and the role of rTSA. As presented in Table II, all 6 studies evaluating rTSA showed a favorable cost-effectiveness profile when using a willingness-to-pay threshold <$100,000/quality-adjusted life-year (QALY).[1,9,11,18,21,35] Renfree et al[35] prospectively analyzed outcomes in patients with cuff tear arthropathy and subsequent pseudoparalysis, demonstrating rTSA to be cost-effective at 2 years postoperatively with a cost utility of $26,920/QALY. One study comparing HA vs. rTSA for the treatment of cuff tear arthropathy found rTSA to be slightly more effective but costlier, with an average additional cost of $11,000. Despite this, rTSA remained cost-effective, with a cost utility of $94,118/QALY gained. Sensitivity analysis demonstrated relative sensitivity in particular to implant prices, with an adjustment in price per reverse total shoulder implant from $12,000 to <$7000 resulting in the cost utility falling below $50,000/QALY.[9] Kang et al[18] demonstrated that HA is "dominated" by (both costlier and less effective than) rTSA for the treatment of massive irreparable rotator cuff tears. When compared with physical therapy alone, rTSA proved to be cost-effective, with a cost utility of $25,522/QALY gained.[18] Two studies compared arthroscopic rotator cuff repair (aRCR) vs. rTSA specifically for the treatment of symptomatic massive rotator cuff tears in patients without evidence of glenohumeral osteoarthritis. Both studies demonstrated rTSA to be cost-effective; however, aRCR was the more cost-effective strategy.[11,21] Specifically, Dornan et al[11] found aRCR with revision to rTSA on potential failure to be more cost-effective than primary rTSA alone. However, this analysis was performed with the assumption that the health utility of aRCR and health utility of rTSA are identical. Sensitivity analysis demonstrated rTSA to be the more cost-effective treatment option when the health utility of rTSA was valued >0.04 QALY/yr over aRCR. Makhni et al[21] showed initial aRCR to be "dominant" (both more effective and less costly) over primary rTSA with a total cost savings >$15,000. Reverse TSA became more cost-effective only under the scenario of high rates of retear following aRCR and subsequently high rates of progression to cuff tear arthropathy. Bachman et al[1] compared the cost-effectiveness of shoulder arthroplasty vs. total hip arthroplasty (THA). THA for the treatment of hip osteoarthritis was calculated to be 2-3 times more cost-effective than rTSA for the treatment of cuff tear arthropathy. However, when only shoulder-specific functionality was included, the QALY value increased from 2.0 to 2.8 years with a subsequent decrease in cost per QALY from $11,100/QALY initially to $8100/QALY, which was compared against $3900/QALY for THA. Bachman et al concluded that rTSA is cost-effective given that the cost per QALY is well below the accepted standard threshold of $50,000 cost/QALY.

## Shoulder arthroplasty for treatment of glenohumeral osteoarthritis

Two studies specifically focused on comparing the cost-effectiveness of shoulder HA vs. TSA for the treatment of glenohumeral osteoarthritis.[2,23] Mather et al[23] showed that TSA as a treatment strategy dominated HA, being both more effective, with an incremental QALY gain of 0.77, and less costly, with a total cost savings of $1970 over the lifetime of a patient. The cost-effectiveness ratio was reported as $957/QALY for TSA vs. $1194/QALY for HA. Bhat et al[2] focused on comparing HA vs. TSA for glenohumeral osteoarthritis in younger patients, aged 30-50 years. They demonstrated primary TSA to be the more cost-effective treatment strategy, with an overall incremental 1.41 QALYs gained for TSA relative to HA and incremental cost-effectiveness ratios of $2989/QALY calculated for primary TSA and $3832/QALY calculated for primary

**Table II** Summary of included cost-analysis studies

| Study | Type of analysis | Study design | Area of analysis | Major findings |
|---|---|---|---|---|
| Makhni et al[21] (*Arthroscopy*, 2016) | CUA | Computer simulation model | Comparison of nonoperative treatment, aRCR, and rTSA for treatment of symptomatic large and massive RTC tears without CTA | Initial aRCR was the most cost-effective strategy, dominating primary rTSA with a cost savings of $15,200 and QALY gain of 0.01. When compared with nonoperative treatment, both aRCR and rTSA were deemed cost-effective, with ICERs of $16,100/QALY and $36,700/QALY, respectively. |
| Coe et al[9] (*JSES*, 2012) | CUA | Markov model | Comparison of HA vs. rTSA for treatment of CTA | Reverse TSA was more effective but more expensive, with an average additional cost of $11,000 and a QALY gain of 0.12 when compared with HA. Regarding the ICER, rTSA was deemed cost-effective, with an incremental cost per QALY gained of $94,118 when a cutoff of $100,000/QALY was used. Sensitivity analyses showed cost-effectiveness to be sensitive to the complication rate, utility of each procedure, and implant price. |
| Kang et al[18] (*Orthopedics*, 2017) | CUA | Markov model | Comparison of PT, AD-BT, rTSA, and HA for treatment of massive irreparable RTC tears | Reverse TSA was the most cost-effective treatment option. Although rTSA was associated with the highest average cost, it provided the highest QALY gained, at 7.7. When compared with PT alone, rTSA proved to be cost-effective, with a cost utility of $25,522/QALY, well below the WTP threshold of $<$$50,000/QALY. |
| Dornan et al[11] (*Arthroscopy*, 2017) | CUA | Markov model | Comparison of aRCR vs. rTSA for treatment of massive RTC tears and pseudoparalysis without GHOA | Primary aRCR was the favorable initial treatment option for patients with pseudoparalysis. The most cost-effective strategy was aRCR with revision to rTSA on potential failure. When compared with primary rTSA, aRCR with revision to rTSA dominated, with an expected cost savings of $18,239.14 and incremental effectiveness of 0.38 QALY. Sensitivity analyses showed primary rTSA to be the cost-effective treatment option when the health utility of rTSA exceeded the utility of aRCR by $>$0.04 QALY/yr. |
| Renfree et al[35] (*JSES*, 2013) | CUA | Longitudinal cohort | Evaluation of costs and outcomes associated with rTSA for CTA | Reverse TSA for patients with CTA was cost-effective, with a significant increase in QALYs at 1 and 2 yr and a cost utility at 2 yr postoperatively of $26,920/QALY based on the SF-6D and $16,747/QALY based on the EQ-5D. |
| Mather et al[23] (*JSES*, 2010) | CUA | Markov model | Comparison of HA vs. TSA for treatment of GHOA | TSA dominated HA, resulting in an overall cost savings of $1970 while providing an incremental QALY gain of 0.77. TSA was less costly and more effective and, subsequently, was the more cost-effective treatment option for GHOA. |

(*continued on next page*)

**Table II** Summary of included cost-analysis studies (*continued*)

| Study | Type of analysis | Study design | Area of analysis | Major findings |
|---|---|---|---|---|
| Bhat et al[2] (*CORR*, 2016) | CUA | Markov model | Comparison of cost-effectiveness of HA vs. TSA for treatment of GHOA in patients aged 30-50 yr | Treating end-stage arthritis in young individuals (age 30-50 yr) with primary TSA vs. HA resulted in greater cost savings, decreased overall revision rates, a greater number of patient-reported satisfactory years, and greater QALYs gained. TSA provided an incremental 1.41 QALYs gained relative to HA. Both HA and TSA were deemed cost-effective for GHOA, with cost-effectiveness ratios of $3832/QALY gained and $2989/QALY gained, respectively. |
| Nwachukwu et al[28] (*JSES*, 2016) | CUA | Markov model | Comparison of cost-effectiveness of nonoperative management vs. HA and rTSA for treatment of complex proximal humeral fractures | Both HA and rTSA were cost-effective strategies for the management of complex proximal humeral fractures when compared with nonoperative care. However, differences in cost-effectiveness were noted when the analysis was performed from a payer vs. hospital perspective. From a payer perspective, HA was dominated by (both costlier and less effective than) rTSA, making rTSA the preferred strategy. When compared with nonoperative management, rTSA resulted in an ICER of $8100/QALY. From a hospital perspective, although HA was less effective, it had a lower cost per QALY ($36,700/QALY gained) whereas rTSA demonstrated an ICER of $57,400/QALY gained over HA. |
| Bachman et al[1] (*WJO*, 2016) | CUA | Markov model | Comparison of rTSA vs. THA cost-effectiveness | Including only shoulder-specific Short Form 36 physical function questions, rTSA QALY scores improved from 2.0 to 2.8 and cost per QALY fell to $8100. THA was 2-3 times more cost-effective than rTSA at a cost per QALY of $3900. This was well under the standard WTP threshold of $<$$50,000 indicating cost-effectiveness of rTSA for the management of CTA. |

*CUA*, cost-utility analysis; *aRCR*, arthroscopic rotator cuff repair; *rTSA*, reverse total shoulder arthroplasty; *RTC*, rotator cuff; *CTA*, cuff tear arthropathy; *QALY*, quality-adjusted life-year; *ICER*, incremental cost-effectiveness ratio; *JSES*, *Journal of Shoulder and Elbow Surgery*; *TSA*, total shoulder arthroplasty; *HA*, hemiarthroplasty; *PT*, physical therapy; *AD-BT*, arthroscopic débridement with biceps tenotomy; *WTP*, willingness to pay; *GHOA*, glenohumeral osteoarthritis; *SF-6D*, Short Form 6 Dimension; *EQ-5D*, EuroQol; *TSA*, total shoulder arthroplasty; *CORR*, *Clinical Orthopaedics and Related Research*; *WJO*, *World Journal of Orthopedics; THA*, total hip arthroplasty.

HA when comparing both with a base-case scenario of glenohumeral arthritis.

## Shoulder arthroplasty for treatment of proximal humeral fractures

One study focused on comparing nonoperative management vs. HA and rTSA for the management of proximal humeral fractures.[28] Both arthroplasty options were deemed cost-effective treatment options for complex proximal humeral fractures when compared with nonoperative management. Differences in cost-effectiveness appeared when the analysis was conducted from a payer vs. hospital perspective. From a payer perspective, rTSA dominated HA by being both more effective and less costly; thus, the authors deemed HA a ‘‘cost-ineffective strategy.’’ Compared with nonoperative care, rTSA resulted in an incremental cost-effectiveness ratio of $8100/QALY. From a hospital perspective, however, HA had a lower cost per QALY gained but was less effective than rTSA. Specifically, HA demonstrated a $36,700/QALY gain

over nonoperative management, whereas rTSA demonstrated a $57,400/QALY gain over HA, making rTSA cost-effective when considering the $100,000 willingness-to-pay threshold.[28]

## Quality of identified studies

The average QHES score was 86.22 ± 13.39 points. Bivariate analysis of factors associated with achievement of low- or high-quality QHES scores was severely limited by sample size, given a total of only 9 included studies. Nonetheless, failure to include 3%-5% annual cost discounting rates was found to be significantly associated with a low-quality QHES score (n = 2, $P = .03$) (Table III). When the achievement of each QHES criteria was analyzed with respect to low- and high-quality QHES scores, studies that appropriately discussed the magnitude and direction of potential biases were associated with a high-quality score (n = 2, $P = .03$). No other significant predictors of low- or high-quality QHES scores were found, with $P$ values ranging from .17 to >.999 (Table IV).

## Discussion

Through this review, we aimed to tackle 3 tasks: (1) provide a comprehensive review of the CEA literature pertaining to shoulder arthroplasty, (2) critically evaluate the collective quality of published studies, and (3) identify any predictors of high-quality studies. We found that the overall quality of the published CEA literature pertaining to shoulder arthroplasty based on the QHES checklist is good. However, there remains a paucity of overall studies published.

**Table III** Factors associated with QHES scores < 25th and > 75th percentile

| Study characteristic | Inclusion rate, % | *P* value* | |
|---|---|---|---|
| | | Association with score < 25th percentile | Association with score > 75th percentile |
| Randomized cohort data | 22.22 | .86 | |
| Cohort size > 100 patients | 22.22 | .42 | |
| Sensitivity analysis | 88.89 | .22 | |
| Societal perspective | 77.78 | | .42 |
| Cost discounting | 77.78 | .03† | |
| Incremental analysis | 100 | | |
| Funding disclosure | 44.44 | | .44 |
| Markov modeling | 77.78 | .42 | |

*QHES*, Quality of Health Economic Studies.
* Two-sided Fisher exact *P* value.
† Statistically significant ($P < .05$).

**Table IV** Factors associated with high-quality score achievement

| Study characteristic | Inclusion rate, % | *P* value |
|---|---|---|
| 1. Clear, specific measurable objective | 100 | |
| 2. Perspective stated | 77.78 | |
| 3. Variable estimates from best source | 77.78 | |
| 4. Subgroup analysis stated | 100 | |
| 5. Sensitivity analysis | 100 | |
| 6. Incremental analysis | 100 | |
| 7. Data abstraction (health states) | 100 | |
| 8. Analytical horizon | 77.78 | |
| 9. Appropriate cost measure | 88.89 | |
| 10. Primary outcome | 66.67 | |
| 11. Valid and/or reliable scales | 100 | .5 |
| 12. Clear economic model | 100 | |
| 13. Clear choice, assumptions, and limitations | 100 | |
| 14. Direction and magnitude biases | 22.22 | .03* |
| 15. Conclusions justified | 88.89 | |
| 16. Funding disclosure | 44.44 | .17 |

* Statistically significant ($P < .05$).

Our hypothesis was thus only partially correct, accepting the part of the hypothesis stating that there would be a deficiency in the amount of literature but rejecting the part of the hypothesis stating that the overall quality of literature would be poor.

Recently, there has been a growing emphasis on the publication of high-level cost-effectiveness analyses within the field of orthopedic surgery, especially as the US health care system moves toward a value-based approach.[4-6,20,26] Two previous studies by Brauer et al[5,6] reviewed the CEA literature published between 1976 and 2003 across the entire field of orthopedics. These reviews exposed the lack of high-quality, consistent economic analyses within orthopedics, especially when compared with other areas of medicine, stating that economic analyses will become more and more important to orthopedic surgeons, with implications affecting reimbursement and policy decision making within the field. Since then, multiple reviews evaluating the CEA literature have been published within several subspecialty fields of orthopedics, including spine care, trauma, hip and knee arthroplasty, and sports medicine.[8,25,27,29,30] Specifically looking at shoulder surgery, Black et al[3] reviewed several previously published cost-analysis studies pertaining to all fields of shoulder surgery, including the treatment of rotator cuff tears and adhesive capsulitis, as well as arthroplasty. They advocated a continued increase in transparent cost and outcome reporting in efforts to increase cost-effectiveness

research publication and thus provide the most value-based care possible for shoulder disorders. Kuye et al[19] performed a systematic review in 2012 specifically looking at the quality of published economic studies on shoulder disorders. They found 32 published studies worldwide between 1980 and 2010, spanning 8 different shoulder pathologies, with 69% of studies published between 2000 and 2010 and >50% published between 2005 and 2010. They evaluated the quality of studies based on the 6 established principles of health economics reported by Udvarhelyi et al[41] and found that all 6 principles were addressed in <25% of studies. They concluded that despite the rapid increase in economic evaluations in shoulder care, there is still an overall lack of quantity and especially quality in cost-effectiveness research.[19]

To our knowledge, no previous review has focused solely on the cost-analysis literature as it pertains specifically to shoulder arthroplasty. Through this review, we found shoulder arthroplasty in general to be a cost-effective intervention. Reverse TSA is a cost-effective treatment option for cuff tear arthropathy. Reverse TSA appears to be more cost-effective than both nonoperative treatment and HA, nearing the cost-effectiveness of THA when considering shoulder-specific quality of life. When dealing with massive rotator cuff tears, both arthroscopic repair and rTSA appear to be cost-effective treatment options; however, the more cost-effective treatment is highly dependent on and particularly sensitive to the assigned health utility of both treatments, as well as the rate of cuff retear and eventual progression to cuff tear arthropathy when initially treated with aRCR. When dealing with glenohumeral osteoarthritis, shoulder arthroplasty appears to be cost-effective, with TSA being more cost-effective than HA. Shoulder arthroplasty for the treatment of proximal humeral fractures is cost-effective when compared with nonoperative treatment. The more cost-effective treatment option between rTSA and HA depends on the financial perspective (payer vs. hospital).

On the basis of the studies reviewed, the average QHES score was 86.22 points. Unfortunately, there is no established cutoff for high- vs. low-quality scoring based on the QHES instrument itself. Despite this, several previous studies within orthopedics have used a cutoff score of 85 points to define studies as high quality.[25,29,30] We noted the QHES scores of the studies included our review to be consistently higher than those in other reviews reported within the literature.[8,25,27,29,30] This finding likely represents an inherent product of increased quality of published economic studies with increased adherence to study design and methodology recommendations put forth by the US Panel on Cost-Effectiveness in Health and Medicine.[37] For this reason, instead of using a cutoff score of 85 points, we examined the distribution of QHES scores and determined a low-quality score to be below the 25th percentile (<82 points) and a high-quality score to be above the 75th percentile (>94 points).

On the basis of our scale, an average QHES score of 86.22 points suggests that there is a relatively high level of quality with respect to the economic analyses in the shoulder arthroplasty literature. Of the 9 reviewed studies, 6 were deemed high quality. Discussing the magnitude and direction of potential bias within studies was the only checklist item associated with achievement of a high-quality score. It is interesting to note that only 2 studies (22%) explicitly discussed this issue, and both achieved the highest QHES scores among the included studies (97 points). This finding is significant as discussing potential biases surrounding a study is crucial to its validity. Because reported outcomes in cost analyses are based on hypothetical models of clinical scenarios, both the internal validity and external validity of these analyses rely heavily on unbiased input data. Although relatively underpowered (N = 9), this finding suggests that economic studies may potentially be screened for discussions of bias as a marker of high-quality studies. Other factors that comprise the QHES instrument, such as sources of funding and perspective of analysis, reported in only 45% and 78% of studies, respectively, had no significant association with the level of quality of studies, despite being highly critiqued methodologic items in cost analyses. In particular, study perspective (ie, societal, payer, or hospital) has the potential to drastically influence the appearance of cost-effectiveness of a particular intervention. Using the societal perspective is the gold standard and accounts for all costs surrounding an episode of medical care, including direct medical and nonmedical costs, as well as all indirect costs. We were unable to report a significant association between a societal-perspective analysis and subsequent quality of the study when further analyzed. Likewise, disclosing sources of funding, which can have a significant effect on the validity of a study, was not associated with the quality level of studies. On the other hand, we found an association between absent cost discounting and lower QHES scores. This finding suggests that studies failing to include cost discounting may be devoid of other QHES checklist items, and thus, this could be used as a marker of low-quality studies.

We believe the value of cost-effectiveness research within the field of orthopedics—and in particular shoulder surgery—is critical as considerations of cost have become emphasized more heavily within our health care system. Cost-effectiveness literature has the ability to critically evaluate new technology or a new intervention with significant implications regarding its subsequent implementation and coverage. Thus, the overall quantity of economic analyses pertaining to shoulder care should be assessed, but it is arguably more important that we appraise the quality of published studies that subsequently have the potential to dictate health care policy. This, however, can become a precarious task as most reviewers of economic analyses lack formal training, which precludes them from objectively grading these studies.[39] For instance, a survey conducted among European decision makers found that a majority do not feel well versed in the health economic-analysis literature

despite relying on it to formulate policy.[15] Thus, it is critical that these analyses are formally reviewed and rated in a systematic fashion. The QHES instrument affords the ability to quickly assess the quality of CEA literature with data supporting its content validity.[8,31]

## Limitations

This review has several limitations. First and foremost, as is inherent to systematic reviews, there is a possibility that relevant studies were missed during the literature search and thus were not included. QHES scoring is subjectively measured and thus may vary depending on the scorer. Although this introduces subjectivity bias, subjective scoring is inherent to all economic grading instruments and is thus not unique to the QHES instrument.[14] We mitigated subjectivity in scoring by having 2 well-trained reviewers independently score each study, with consensus on the final score following discussion.

As mentioned previously, the small number of included studies limits the statistical conclusions made by this study. Because of limited variability among the various parameters within the QHES instrument, we were unable to conduct a more comprehensive analysis with respect to factors predictive of achievement of high and low scores. Analysis was thus limited to only criteria in which there was true variance. As a result, the significance of factors associated with the quality of studies should be interpreted with caution. Furthermore, the determination of the scores defined as low and high quality was based on a limited distribution of data, using statistical modeling to identify threshold values. Multiple methodologies may be used to define thresholds of low- and high-quality studies, and unlike patient-reported outcome data, it remains unclear what minimum threshold difference in the QHES score represents a significant difference in quality.

The QHES instrument requires yes or no responses to the checklist items, as opposed to a continuous scoring system for each item. This all-or-none phenomenon may prevent some studies from achieving a higher-quality score as partial attainment of a criterion typically results in 0 points as opposed to partial credit. Additionally, as Nwachukwu et al pointed out, the QHES instrument may suffer from a ceiling effect, meaning that as economic analyses become more commonplace and evolve, there may be a need to implement more sophisticated appraisal criteria to help further differentiate high-quality studies from lower-quality studies.[25]

Many of the checklist items comprising the QHES scale pertain to reporting of the quality of results based on methodology rather than the actual validity of a study. This can become problematic when trying to differentiate between a study's quality and its validity. For instance, one of the checklist items deals with funding sources of studies. If a study reports the source of funding, then it receives the full allotted points irrespective of the presence of a biased funding source, such as industry. Additionally, the thoroughness of sensitivity analyses performed within a study cannot be deciphered using the QHES instrument as all studies receive the full allotted points if a sensitivity analysis was performed, irrespective of its thoroughness. In general, sensitivity analyses arguably comprise one of the most important aspects of economic modeling as they address the concept that small changes in probabilities of the model could have drastic effects on the final results of the analysis. Finally, the perspective of the economic analysis (ie, societal, payer, or hospital) has important implications and can change the results and thus the conclusions made regarding the cost-effectiveness of an intervention being studied. This was the case in the cost analysis by Nwachukwu et al,[28] in which the more cost-effective procedure between HA and rTSA for the treatment of complex proximal humeral fractures depended on the perspective of the analysis (hospital vs. payer). The QHES instrument only requires that a study list and explain the perspective of the analysis to receive the full allotted points, rather than points being given based on the sophistication of the perspective analysis. These aforementioned examples are inherent to most simple checklists that are used to score or grade complex topics rather than unique limitations to the QHES tool. Despite this, the QHES instrument remains, to our knowledge, the only validated objective scoring tool available to assess the quality of the health economic-analysis literature. We do not believe, however, that the QHES instrument should be used as a surrogate for a detailed critical review and assessment by experts. Rather, the QHES instrument can be most valuable as a tool used to critically evaluate the quality of all available literature pertaining to a certain therapy, technology, or intervention and provide a conglomerate score for interpretation. This allows reviewers to assess whether the CEA literature pertaining to a particular health care topic is lacking in quality or not. Furthermore, this helps reviewers to stratify studies based on their quality score and to potentially help isolate higher-quality studies that can subsequently be reviewed more thoroughly, which is especially important when using CEA literature to determine policy or decision making. Along these lines, as suggested by Ofman et al,[31] the QHES instrument could be used by journal editors as a proxy screening tool to only review certain cost analyses that meet a particular quality score.[31] Secondarily, the QHES instrument also provides a valuable framework for the development of high-quality future cost-analysis studies.

## Conclusion

Shoulder arthroplasty is a cost-effective procedure when used to treat a multitude of shoulder pathologies. The

overall quality of the cost-analysis literature in shoulder arthroplasty is relatively good, with an average QHES score of 86.22 points. Studies failing to include an annual cost discounting rate are more likely to score below the 25th percentile (ie, low quality), whereas those including a discussion of the magnitude and direction of potential biases are more likely to achieve a score in excess of the 75th percentile (ie, high quality).

## Disclaimer

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## Supplementary data

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