Cost-Effectiveness of Arthroscopic Rotator Cuff Repair Versus Reverse Total Shoulder Arthroplasty for the Treatment of Massive Rotator Cuff Tears in Patients With Pseudoparalysis and Nonarthritic Shoulders

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Purpose: To determine the most cost-effective treatment strategy for patients with massive rotator cuff tears and pseudoparalysis of the shoulder without osteoarthritis of the glenohumeral joint (PP without OA). Specifically, we aimed to compare arthroscopic rotator cuff repair (ARCR) versus reverse total shoulder arthroplasty (RTSA) and investigate the effect of patient age on this decision. **Methods:** A Markov decision model was used to compare 3 treatment strategies for addressing PP without OA: (1) ARCR with option to arthroscopically revise once, (2) ARCR with immediate conversion to RTSA on potential failure, and (3) primary RTSA. Hypothetical patients were cycled through the model according to transition probabilities, meanwhile accruing financial costs, utility for time in health states, and disutilities for surgical procedures. Utilities were derived from the Short Form-6D scale and expressed as quality-adjusted life-years. Model parameters were derived from the literature and from expert opinion, and thorough sensitivity analyses were conducted. TreeAge Pro 2015 software was used to construct and assess the Markov model. **Results:** For the base-case scenario (60-year-old patient), ARCR with conversion to RTSA on potential failure was the most cost-effective strategy when we assumed equal utility for the ARCR and RTSA health states. Primary RTSA became cost-effective when the utility of RTSA exceeded that of ARCR by 0.04 quality-adjusted life-years per year. Age at decision did not substantially change this result. **Conclusions:** Primary ARCR with conversion to RTSA on potential failure was found to be the most cost-effective strategy for PP without OA. This result was independent of age. Primary ARCR with revision ARCR on potential failure was a less cost-effective strategy. **Level of Evidence:** Level IV, economic and decision analysis.

The prevalence of full-thickness rotator cuff tears (RCTs) in the general population has been reported to be about 20%, with one-third of these RCTs being symptomatic.[1,2] In the United States, more than 275,000 rotator cuff repairs (RCRs) of symptomatic RCTs are being performed every year, and the frequency is increasing.[3,4] Approximately 25% of RCTs are massive rotator cuff tears (MRCTs) with

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The authors report the following potential conflict of interest or source of funding: P.J.D. received a grant from Arthrex; payment for lectures including service on speakers' bureaus from Arthrex; and royalties from Lippincott Williams and Wilkins and Arthrex. S.S.B. received consultancy fees, inventor's royalties, payment for lectures including service on speakers' bureaus, and travel accommodations/meeting expenses from Arthrex. P.J.M. receives research support from Steadman Philippon Research Institute; is a paid consultant for Arthrex and receives royalties from Arthrex and Medbridge; has stock or stock options in GameReady and VuMedi; and receives research support from Steadman Philippon Research Institute. Corporate sponsorship for Steadman Philippon Research Institute is received from Smith & Nephew, Arthrex, Siemens, Ossur, and Vail Valley Medical Center.

Received March 3, 2016; accepted August 25, 2016.

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0749-8063/16173/$36.00
http://dx.doi.org/10.1016/j.arthro.2016.08.028

involvement of 2 or more tendons or a tear dimension of >5 cm.[5,6] The surgical treatment of MRCTs is challenging, with treatment options ranging from arthroscopic repair to reverse total shoulder arthroplasty (RTSA).[7]

Pseudoparalysis (PP) represents a condition of the shoulder with active elevation of less than 90° in association with full passive elevation.[8,9] Almost 20% of patients with MRCTs are affected by PP, and it has been shown previously that PP can be reversed effectively with arthroscopic RCR (ARCR).[8-12] Although RTSA initially was introduced as a treatment option for cuff tear arthropathy, the indications for RTSA have expanded to include the treatment of MRCTs with PP and without osteoarthritis (OA).[13-17] In fact, RCTs recently were identified as the second most common indication (21%) for RTSA implantations in the United States.[18]

These 2 treatment options for PP without OA, ARCR, and RTSA have their own potential limitations. ARCR for MRCTs has been shown previously to be associated with fairly high rates of retear (especially with increasing initial tear size) and with associated deterioration of functional outcomes.[19-22] RTSA, in contrast, can result in complications that include dislocation, scapular notching, and baseplate loosening in addition to infection. Moreover, limited information currently is available on long-term survivorship after RTSA,[15,16,23] and many experts suggest that RTSA should be reserved for elderly patients.[7,24]

Therefore, the best treatment for patients with PP without OA remains unclear. Although some surgeons prefer ARCR, others advocate RTSA for this condition. As the result of increasing medical costs, the cost-effectiveness of orthopaedic procedures increasingly is gaining importance in the current health care climate.[25] The aim of this study was to determine the most cost-effective treatment strategy for patients with MRCTs and PP without OA. Specifically, we aimed to compare ARCR versus RTSA and investigated the effect of patient age on this decision. We hypothesized that ARCR would be more cost-effective than RTSA for the treatment of PP without OA.

Methods

Markov Decision Modeling for Cost-Effectiveness

Markov decision modeling is a tool that aids in clinical decision-making and in health care policy for problems in which outcomes are dependent partially on treatment choice and dependent partially on chance. It is particularly apt in contexts in which both societal monetary cost and patient outcome are of principal interest. The mechanism of the Markov decision process is to model a hypothetical cohort of patients as they transfer among possible health states according to transition probabilities, meanwhile accruing financial costs for treatment, and utility that represents overall health-related quality of life (HRQoL). Two or more treatment approaches can then be compared on the basis of cost, health benefit, or cost-effectiveness.

Model Structure and Computation

Our decision model considered 3 competing treatment strategies for patients with MRCT and PP without OA: (1) ARCR with the option to revise once with ARCR for potential failure; (2) ARCR with immediate conversion to RTSA for potential failure; and (3) primary RTSA. Hypothetical patients in Strategy 1 can transition through up to 6 distinct health states in sequential order: ARCR, revision ARCR, RTSA, revision RTSA, failed revision RTSA, and death. Treatment Strategies 2 and 3 allow patients to exist in 4 and 5 of the aforementioned states, respectively. A conceptual flow chart of the model can be found in Figure 1.

Each cycle through the model represents 1 postsurgical year, wherein a patient can either remain in his or her current health state, transition into the next health state, or perish from all-cause mortality. To transition to the next state, a patient must first undergo a surgical complication. A probabilistic subset of these surgical complications is defined as failures requiring conversion to the subsequent health state. Patients in the hypothetical cohort are subject to all-cause mortality risk according to the 2010 U.S. life tables reported by the Centers for Disease Control and Prevention,[26] and the model cycles continue until the entire cohort has entered the death state. Individual-level patient heterogeneity was not incorporated, which allowed for analytical computation of the model rather than needing to simulate individual hypothetical patients. This method of Markov model evaluation is commonly termed "cohort simulation." The model was built and analyzed with the software TreeAge Pro Healthcare 2015.[27]

Model Parameters and General Assumptions

A thorough search of the literature was performed to guide estimation of important model parameters. Evidence was preferred based on the following hierarchy: (1) quantitative synthesis of multiple high-quality research papers, (2) findings from other cost-effectiveness studies, (3) evidence from individual high-quality studies, and (4) expert opinion. The "base-case" scenario includes each model parameter at its estimated value. One- and two-way sensitivity analyses were performed to explore the dependence of the model results on key parameter values differing from the base case.

It generally was assumed that patients in treatment Strategies 1 and 2 who converted to RTSA exhibited the same quality of life and surgical complication probabilities as patients in Strategy 3 who had primary RTSA. In other words, there was no memory effect of past health states or surgical procedures. Evidence for this

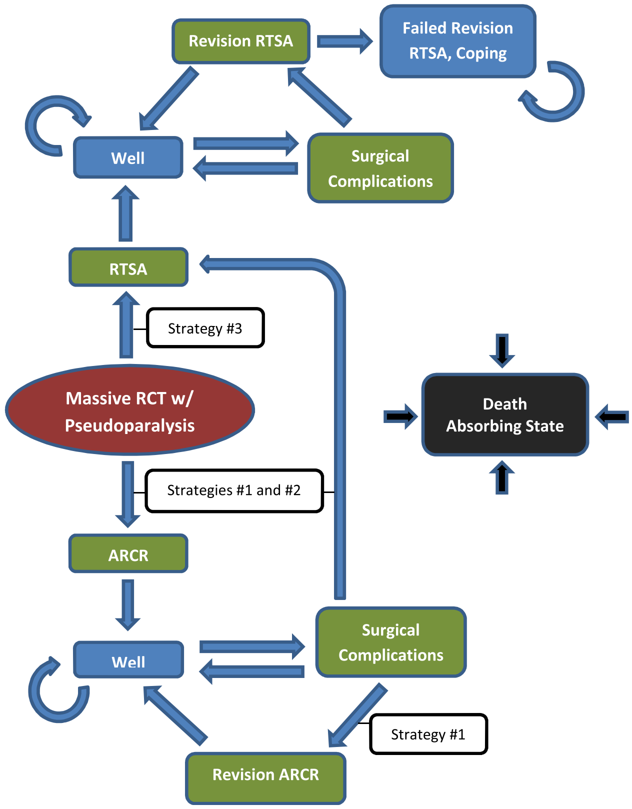

Fig 1. Conceptual patient flowchart of the Markov decision model. A hypothetical cohort of patients with massive RCTs and pseudoparalysis start in the red oval and progress through condition states (blue rectangles) via surgical interventions (green rectangles) according to yearly transition probabilities. Patients cycle through the model accruing costs, utilities, and disutilities until all-cause death. Patients in Strategy 1 remain in the lower portion of the chart to undergo 1 revision ARCR on potential failure before transitioning to RTSA. (ARCR, arthroscopic rotator cuff repair; RCT, rotator cuff tear; RTSA, reverse total shoulder arthroplasty.)

assumption was found in Mulieri et al.[28] The model did not allow for multiple surgical complications in a single year, and all per-year transition probabilities were distributed uniformly over the course of the year.

Patient Age and Other Characteristics

Age is an important factor in patient selection for RTSA, and initial recommendations were to limit the use of RTSA to patients 70 years of age and older[24,29]; however, as RTSA has been expanded to other indications and has gained more widespread acceptance, the use of RTSA has expanded to younger patients.[29,30] Thus, starting age was of particular interest when we developed and evaluated the model. The base case patient age was chosen as 60 years, an age that the senior authors determined to be a common and crucial age for which this decision is made in practice, and a sensitivity analysis was performed to consider patients between 45 and 85 years of age. The studies that influenced our selected parameters were cohorts containing a variety of patient demographics, injury patterns, and comorbidities. Our model results are therefore generalizable to the same extent.

Costs

Cost data were averaged from 6 cost-effectiveness studies, 3 of which investigated ARCR and 3 RTSA.[31-36] Each of these studies compiled direct societal costs as recommended by the Panel on Cost-effectiveness in Health and Medicine.[37] Mather et al.[33] additionally included several indirect costs resulting in a slightly greater estimated ARCR cost. There was a high degree of agreement on cost for ARCR and RTSA among these 6 studies. All past cost estimates were appreciated at 3% per year to 2016 dollars. Likewise, all future costs incurred in the model were discounted at 3% per year to 2016 dollars. As suggested by the findings in Genuario et al.,[32] revision ARCR and complications from revision ARCR were assumed to be 5% greater than their primary counterparts.

Utilities

Utility was defined as HRQoL as derived from the Short Form (SF)-6D scale. HRQoL experienced over time accumulates into quality-adjusted life-years (QALYs), which is the ultimate effectiveness metric in cost-effectiveness studies. When relevant studies reported physical and mental component summaries of the SF-12 or SF-36 scales, HRQoL was converted to the SF-6d scale by use of the methods in Hanmer.[38] One study that otherwise met the inclusion criteria reported EuroQol-5D, another HRQoL scale.[31] We did not include these data because it has been shown that the EuroQol-5D measures different psychometric properties and a different aspect of HRQoL than the SF-6d, resulting in a clinically significant lack of agreement.[39]

The 2 studies we included for RTSA utility reported on largely female (approximately 75%) and elderly (mean age 75 years) samples and found a mean HRQoL of 0.68 after RTSA.[28,40] Four studies reported on samples of relatively younger (mean age 55 years) and predominantly male (approximately 43% female) undergoing ARCR to find an average HRQoL of 0.78.[33,41-43] To overcome the difference in age, sex, and HRQoL between the studies reporting utilities for RTSA and ARCR, we chose to present a 2-way sensitivity analysis of utility after RTSA and utility after ARCR as a primary result. Lacking a clear best estimate for utility after RTSA and ARCR in an equivalent patient set, the base case arbitrarily assumed equal HRQoL of 0.78 for both RTSA and ARCR.

On the basis of a survey of the senior authors of this paper (P.J.D., S.S.B., P.J.M.), utility for the revision ARCR and revision RTSA health states was assumed to be 70% that of the corresponding primary surgeries.

Table 1. Model Parameters With Base Case Value and Sensitivity Range

Parameter Description	Name	Base Case Value	Low	High
Age at decision	age_start	60	45	85
Mortality rate by age from U.S. life table	pMortality	U.S. Life Table		
Discount rate of cost	cDiscountRate	0.03	0.01	0.07
Discount rate of utility	uDiscountRate	0.03	0.01	0.07
Cost of ARCR surgery	cARCR	14,983.19	0	25,000
Cost of complications from ARCR	cARCRcomps	12,814.41	0	20,000
Cost of revision ARCR	cReARCR	cARCR * 1.05	0	30,000
Cost of complications from revision ARCR	cReARCRcomps	cARCRcomps * 1.05	0	20,000
Cost of revision RTSA	cReRTSA	22,127.64	0	40,000
Cost of revision RTSA complications	cReRTSAcomps	11,009.36	0	20,000
Cost of RTSA surgery	cRTSA	26,980.34	0	50,000
Cost of RTSA complications	cRTSAcomps	cReRTSAcomps/1.05	0	15,000
Disutility of ARCR	duARCR	−0.02	−0.1	0
Disutility of complications from ARCR	duARCRcomps	−0.05	−0.1	0
Disutility of coping after failed revision RTSA	duFailedReRTSA	0	0	0
Disutility of revision ARCR	duReARCR	duARCR * 1.5	−0.2	0
Disutility of complications from revision ARCR	duReARCRcomps	duARCRcomps * 1.5	−0.2	0
Disutility of revision RTSA (1-time)	duReRTSA	duRTSA * 1.5	−0.2	0
Disutility of complications from revision RTSA	duReRTSAcomps	duRTSAcomps * 1.5	−0.2	0
Disutility of RTSA	duRTSA	duARCR	−0.1	0
Disutility of complications from RTSA	duRTSAcomps	duARCRcomps	−0.1	0
Probability of complications from ARCR	pARCRcomps	0.04146 Yr 1; 0.00297 Yrs 2+	0	0.1
Probability of death from ARCR	pARCRdeath	0	0	0.005
Probability of failure of ARCR	pARCRfail	0.545	0.25	0.75
Probability of complications from revision ARCR	pReARCRcomps	0.10759 Yr 1; 0.02143 Yrs 2+	0	0.15
Probability of death during revision ARCR	pReARCRdeath	0	0	0.005
Probability of failure of revision ARCR	pReARCRfail	0.8	0.5	1
Prob complications from revision RTSA	pReRTSAcomps	0.114	0	0.2
Probability of death during revision RTSA	pReRTSAdeath	0	0	0.01
Probability of failure of revision RTSA	pReRTSAfail	0.333	0	0.66
Probability of complications from RTSA	pRTSAcomps	0.040	0	0.1
Probability of death from RTSA	pRTSAdeath	0	0	0.01
Probability of failure of RTSA	pRTSAfail	0.182	0	0.4
Utility after successful ARCR	uARCR	0.788	0.6	0.9
Utility of coping after a failed revision RTSA	uFailedReRTSA	uReRTSA * 0.5	0	0.5
Utility of successful revision ARCR	uReARCR	uARCR * 0.7	0.4	0.65
Utility of revision RTSA	uReRTSA	uRTSA * 0.7	0.4	0.65
Utility after successful RTSA	uRTSA	0.788	0.6	0.9

NOTE. Some base case values are algebraic expressions of other parameters as defined in the methods section of the text. The low and high columns indicate the range of each parameter used to test whether the ultimate winning strategy remained consistent (1-way sensitivity analysis).

ARCR, arthroscopic rotator cuff repair; RTSA, reverse total shoulder arthroplasty.

The failed revision RTSA state was assumed to achieve half the utility of the successful revision RTSA state.

Disutilities are one-time losses of QALYs incorporated into the model to capture the inconvenience and discomfort of undergoing a surgical procedure. Disutility for ARCR and surgical complications after ARCR has been reported as 0.02 and 0.05 QALYs, respectively.[33] Again, based on expert opinion of the senior authors, disutility was assumed to be the same for ARCR and RTSA procedures, and revision surgeries were assumed to incur 50% more disutility than primary surgeries.

Transition Probabilities

Surgical complication rates for RTSA and ARCR were estimated from 11 relevant studies found in the literature (7 ARCR, 4 RTSA).[9-12,23,28,44-48] Overall complication rates were calculated by pooling patients from all relevant studies together equally. Because long-term complication and failure rates after ARCR and RTSA for MRCTs with PP and without OA are not yet known to the orthopaedic community, expert opinion (P.J.D., S.S.B., P.J.M.) was used to guide the assumed time distribution of these events. The model assumed that 85% of all surgical complications of ARCR were allocated to the first year after surgery with the remaining 15% dispersed evenly across subsequent years, which is supported by findings of yearly longer-term ultrasound follow-up after mini-open RCR.[49] RTSA was assumed to have a constant complication rate across postsurgical time. The model was constructed so that a subset of the surgical complications would probabilistically be defined as failures requiring conversion to the subsequent procedure health state. These

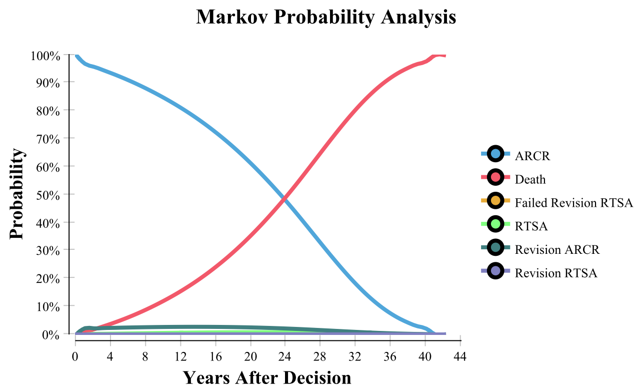

Fig 2. Markov probabilities for Strategy 1. Proportions of hypothetical patients in each of 6 possible health states plotted as a function of years after surgery. Model parameters are set at their base case, including patient age at 60 years. (ARCR, arthroscopic rotator cuff repair; RTSA, reverse total shoulder arthroplasty.)

transition probabilities were derived from the same set of studies. Nonconversion surgical complications included capsular release for shoulder stiffness, debridement and irrigation for superficial wound infections, replacement of the RTSAs polyethylene inlay, and open reduction internal fixation for acromion fracture, whereas rotator cuff retears and implant loosening or deep wound infections requiring the removal of the RTSA were defined as surgical complications requiring conversion.

Model Reporting

The recommendations from the Panel on Cost-Effectiveness in Health and Medicine were followed for all analysis and model reporting.[37] Willingness-to-pay (WTP), interpreted as the maximum amount an individual is willing to sacrifice for 1 additional QALY, was set at the conventional $50,000 level. Base case cost-effective analysis, threshold analyses, and a 2-way sensitivity analysis were conducted to compare the 3 strategies.

Comparisons were made on the basis of 2 commonly reported cost-effectiveness metrics, net monetary benefit (NMB) and the incremental cost-effectiveness ratio (ICER). NMB is defined as E * WTP − C, where E is the expected effectiveness in QALYs, WTP equals $50,000, and C is the expected cost of the treatment. NMB can be calculated separately for each strategy and then compared. The ICER is a metric used specifically when 2 competing strategies are compared. ICER is defined as $(C_1 - C_0)/(E_1 - E_0)$, where C_1 and C_0 are the expected cost, and E_1 and E_0 are the expected effectiveness in QALYs, for the 2 treatments under comparison. ICER is valuable when strategies are compared directly, but when differences in effectiveness are minimal, ICER can become distorted and NMB is then often preferred. Dominance is concluded when one strategy is both less costly and more effective than another competing strategy.

Results

Base Case Cost-Effectiveness

Table 1 presents the set of best parameter estimates that together constitute the "base case." The estimated cost for primary ARCR was $14,983.19, whereas the cost for primary RTSA was $26,980.34. The surgical complication rate during the first year was found to be approximately 4% for both primary ARCR and primary RTSA. Although the complication rate of RTSA remained constant (4% yearly) across postsurgical time, the ARCR complication rate was substantially lower (approximately 0.3%) for subsequent years. Figure 2 details the Markov-modeled probabilities for an average 60-year-old patient undergoing Strategy 1 to be in each health state depending on the number of years postsurgery.

Strategy 3 (primary RTSA) was dominated by Strategy 1 (ARCR with revision ARCR) and Strategy 2 (ARCR with revision to RTSA), indicating that it was both more expensive and less effective for the base case scenario. Relative to the baseline Strategy 1, Strategy 3 had an incremental expected cost of +$18,661.62 and an incremental effectiveness of −0.28 QALYs (Table 2). Meanwhile, dominance was not found for the comparison between Strategies 1 and 2. Strategy 2 had an expected cost relative to Strategy 1 of +$422.47 and an incremental effectiveness of +0.11 QALYs, resulting in an ICER of $3,959.55. This is well below the standard WTP threshold of $50,000/QALY; thus, we conclude that Strategy 2 (ARCR with conversion to RTSA on

Table 2. Base Case Cost-Effectiveness of the 3 Competing Strategies

Strategy #	Strategy	Cost, $	Incremental Cost, $	Effectiveness, QALYs	Incremental Effectiveness, QALYs	ICER, $/QALY	NMB, $
1	ARCR → Re-ARCR	16,581.06		12.44			605,595.20
2	ARCR → RTSA	17,003.53	422.47	12.55	0.11	3,959.55	610,507.60
3	RTSA	35,242.67	18,661.62	12.17	−0.28	−67,460.60	573,102.10

NOTE. Strategy 3 was more costly and less effective and thus dominated by Strategies 1 and 2. Strategy 2 exhibited the greatest NMB and was cost effective relative to Strategy 1 with an ICER of $3,959.55, well under willingness-to-pay = $50,000 per additional QALY. Incremental cost, effectiveness, and cost-effectiveness were calculated relative to Strategy 1. Dollars are 2016 U.S. dollars.

ARCR, arthroscopic rotator cuff repair; ICER, incremental cost-effectiveness ratio; NMB, net monetary benefit; QALY, quality-adjusted life-year; RTSA, reverse total shoulder arthroplasty.

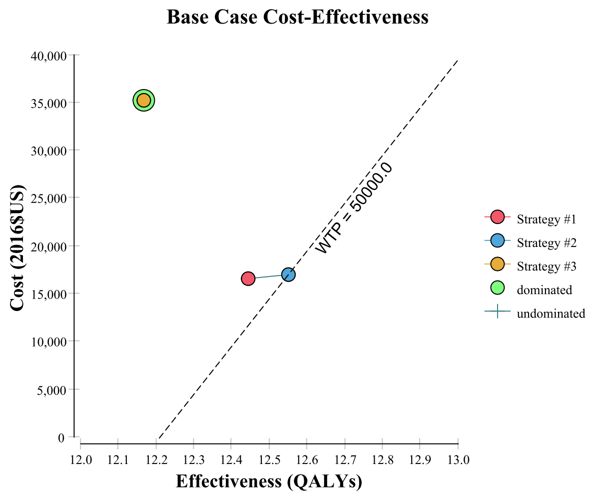

Fig 3. Cost-effectiveness for the 3 competing treatment strategies with model parameters set at the base case scenario. Strategy 3 is both more costly and less effective and thus is dominated by Strategies 1 and 2. Strategy 2 is more effective but slightly more costly than Strategy 1. When a WTP of $50,000 is used, Strategy 2 (ARCR with conversion to RTSA on potential failure) is the preferred strategy. (ARCR, arthroscopic rotator cuff repair; RTSA, reverse total shoulder arthroplasty; WTP, willingness-to-pay.)

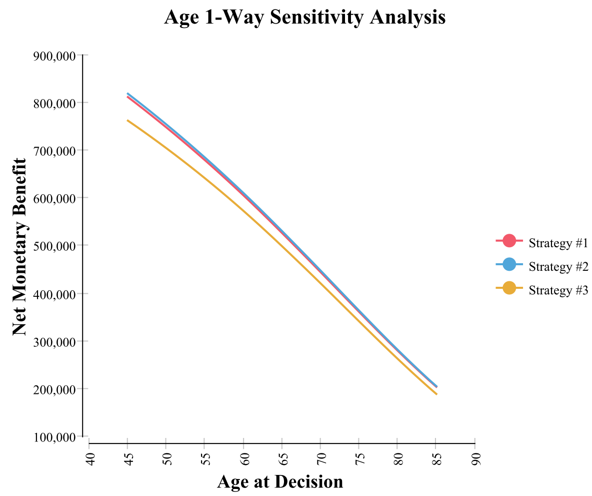

Fig 5. One-way sensitivity plot for age at decision. All other parameters set to their base case value. Strategy 2 provided the highest net monetary benefit for all starting ages 45 to 85 years.

potential failure) is the most cost-effective strategy for the base case. These relationships are visualized in Figure 3.

Utility Sensitivity Analysis

Figure 4 shows the results of the 2-way sensitivity analysis between the utility of primary ARCR and primary RTSA. Across the grid, the colors represent the preferred strategy based on NMB using a WTP of $50,000. Strategy 2 (ARCR with conversion to RTSA on potential failure) was preferred for all situations in which the utility of each treatment was equivalent (diagonal line from lower left corner to upper right). Strategy 3 (Primary RTSA) provided the greatest NMB when the expected utility of RTSA was at least 0.04 QALYs/year greater than the utility of ARCR. Strategy 1 (ARCR followed by revision ARCR on potential failure) was only preferred when the utility of ARCR drastically outperformed the utility of RTSA.

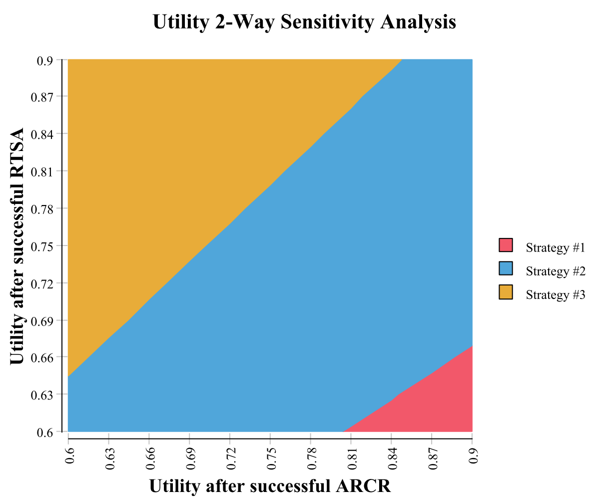

Fig 4. Two-way sensitivity plot for utility of ARCR versus utility of RTSA. Colors represent the preferred strategy for the combination of the 2 parameters based on NMB when a WTP of $50,000 is used. Strategy 2 is the preferred strategy for most plausible combinations of expected ARCR utility and RTSA utility. (ARCR, arthroscopic rotator cuff repair; NMB, net monetary benefit; RTSA, reverse total shoulder arthroplasty; WTP, willingness-to-pay.)

Threshold and 1-Way Sensitivity Analyses

Investigating the role of age in deciding how to treat patients with PP without OA was a primary objective of our study. Figure 5 shows the 1-way sensitivity analysis of age at decision for cost-effectiveness among the 3 treatment strategies. Strategy 2 (ARCR with conversion to RTSA on potential failure) was preferred for all patient ages between 45 and 85 years on the basis of net monetary benefit.

A thorough threshold analysis was conducted to vary each model parameter through its plausible range (see Table 1) individually and test whether the preferred strategy remained constant throughout. Table 3 includes the variables for which the model's treatment recommendation was sensitive. As was illuminated by the 2-way sensitivity analysis mentioned previously, effectiveness and NMB are sensitive to the expected utility of primary ARCR and RTSA. Unsurprisingly, the strategy with the lowest cost was found to depend on the cost of primary and revision ARCR, and primary RTSA. The principal finding of the base case model that Strategy 2 (ARCR with conversion to RTSA

Table 3. Threshold Analysis Detailing Parameters for Which a Value Within Their Sensitivity Range Was Found to Result in Equivalent Markov EV Between 2 Strategies (Comparator and Baseline)

Variable	Base Case	Attribute	Value	Comparator	Baseline	EV
cARCR	14,983.19	Cost	23,794.80	Strategy 1	Strategy 2	25,815.14
cReARCR	cARCR * 1.05	Cost	24,984.54	Strategy 1	Strategy 2	17,003.53
cRTSA	26,980.34	Cost	7,868.51	Strategy 3	Strategy 2	16,130.85
cRTSA	26,980.34	Cost	14,802.89	Strategy 2	Strategy 1	16,447.48
pReARCR complications	0.10759 year 1; 0.02143 tears 2+	Cost	0.0830	Strategy 1	Strategy 2	17,003.53
uARCR	0.788	Eff	0.7627	Strategy 3	Strategy 2	12.167
uARCR	0.788	NMB	0.7389	Strategy 3	Strategy 2	11.462
uRTSA	0.788	Eff	0.8134	Strategy 2	Strategy 3	12.566
uRTSA	0.788	NMB	0.8379	Strategy #2	Strategy 3	12.241

NOTE. All nonlisted model parameters were robust with respect to the most cost-effective strategy throughout their sensitivity range. ARCR, arthroscopic rotator cuff repair; EV, expected value; NMB, net monetary benefit; RTSA, reverse total shoulder arthroplasty.

on potential failure) was the most cost-effective treatment choice was robust to all model parameters not included in Table 3.

Discussion

The most important finding of this Markov decision analysis was that primary ARCR is the favorable initial treatment for patients suffering from PP without OA. The strategy of primary ARCR with conversion to RTSA on potential failure was found to be more cost-effective than the strategy of primary ARCR followed by revision ARCR on potential failure. The relative cost-effectiveness of the 3 strategies investigated was consistent regardless of starting age anywhere between 45 and 85 years of age.

The treatment strategy of primary ARCR followed by revision ARCR on potential failure was less favored by this Markov decision model. This finding is most supported by the fact that outcomes are less favorable after revision ARCR, compared with primary ARCR. Denard et al.[10] found a significantly lower rate of reversal of PP in revision ARCR and significantly inferior mean UCLA score, American Shoulder and Elbow Surgeons Shoulder score, Simple Shoulder Value, and less return to activity compared with primary ARCR for PP without OA. Greater failure and complication rates after revision ARCR than after primary ARCR also have been reported in other studies dealing with treatment of MRCTs with PP without OA.[9,11,12,44] Failure to reverse PP, which was observed in more than 50% of patients after revision ARCR, can be considered a clinical failure and will likely necessitate conversion to RTSA in many patients.

Primary RTSA was the cost-effective treatment path when the utility of RTSA exceeded the utility of ARCR by at least 0.04 QALYs/yr. This may be a relevant situation for patients with more complex situations involving a MRCT and PP without OA. The authors of a current concepts review on RCR in elderly patients summarized that ARCR, independent of the effective age, seems most suitable for symptomatic patients with durations of symptoms of less than 3 years, fatty infiltration of the supraspinatus and infraspinatus grade 1 or 2, cuff tear arthropathy Hamada grade 1 or 2, body mass index <30, and American Society of Anesthesiologists grade 1 or 2.[29] These criteria were derived from situations with full-thickness, single-tendon involvement of the supraspinatus but may likely also affect the treatment success for patients with MRCTs. Greater body mass index and American Society of Anesthesiologists grade recently have been proven to negatively affect the outcomes of RTSA.[50] In cases with longer duration of symptoms and greater grades of fatty infiltration, the primary treatment with a RTSA may be favorable, although ARCR in patients with MRCT and fatty degeneration stages 3 and 4 provided significant functional improvement.[51] Another situation that is likely to benefit from primary RTSA is moderate-to-severe shoulder instability in the context of MRCT with PP. In cases with anterior-superior escape of the humeral head, the primary implantation of a RTSA seems advantageous.[16]

The indications for RTSA versus ARCR for PP without OA have varied in the published literature. Mulieri et al.[28] and Werner et al.[47] reported outcomes of RTSA for “irreparable” MRCTs, whereas Denard et al.,[9,10] Oh et al.,[11] and Miyazaki et al.[12] were clearly able to repair similar MRCTs. There are likely technically irreparable tears and functionally irreparable tears; the former may depend on the skill and experience of the surgeon, whereas the latter depends on the biology of the patient. A RCT originally was described as being irreparable if it involved at least 2 rotator cuff tendons with retraction that is not amenable to mobilization and repair to the anatomic footprint with the arm in less than 60° of abduction.[52] Werner et al.[47] considered a MRCT to be irreparable “if the pseudoparesis was chronic, the acromiohumeral distance” (AHD) “was <7 mm on a plain anteroposterior radiograph made with the shoulder in neutral rotation and fatty infiltration of the supraspinatus and infraspinatus muscles was greater than stage two according to the Goutallier classification." Interestingly, Oh et al.[11] included patients with an AHD of less than 7 mm and stage 3 fatty degeneration or greater of the supraspinatus tendons and/or infraspinatus tendons and showed a 76% rate of reversal of PP after ARCR in 29 patients. Likewise, Denard et al.[9] did not consider AHD <7 mm or stage 3 fatty degeneration a contraindication to repair.

The fact that Strategy 2 (primary ARCR with conversion to RTSA on potential failure) was found to be the most cost-effective strategy for PP without OA, independent of age, is supported by some recommendations in the literature.[9-11] The rates of retear of ARCR for PP without OA described across the literature are substantially lower than the retear rates for MRCTs without PP.[19,41,53] Oh et al.[11] and Denard et al.[9,10] concluded based on their findings that ARCR should be the first-line treatment for PP without OA. In addition, Werner et al.[47] concluded that "because of the high complication rate and the fact that there may be long-term complications that are not yet known" RTSA "should be reserved as a salvage procedure for situations in which an acceptable clinical outcome cannot be expected with another treatment modality." Such a situation may be present in patients with duration of symptoms >3 years and in patients with moderate-to-severe glenohumeral instability due to anterior-superior escape of the humeral head.[16,29] The studies by Oh et al.,[11] Denard et al.,[9] and Werner et al.[47] demonstrate a high variability regarding the judgment of reparability of MRCTs with PP. In this context, it has been postulated previously that primary MRCTs with PP may be most predictably managed by shoulder arthroscopists experienced in advanced mobilization techniques.[10]

Other procedures such as latissimus dorsi transfer and superior capsule reconstruction must be considered as potential alternative treatment options for MRCTs[7]; however, results in the literature for both treatments are sparse in the context of MRCTs with PP. Although patients with pseudoparalytic shoulders have been treated with latissimus dorsi transfer, their specific outcomes remain unclear as they have not been reported separately.[54] Gerber et al.[55] view PP of anterior elevation as exclusion criteria for a latissimus dorsi transfer, and Boileau et al.[56] have suggested the combination of RTSA with latissimus dorsi transfer as a potential treatment option for patient with combined PP in anterior elevation and external rotation. Similar to latissimus dorsi transfer, superior capsule reconstruction has been used in patients with pseudoparalytic shoulders, however, their specific outcomes equally remain unclear.[57]

Limitations

Several limitations exist in this study. First, model assumptions and parameters were determined as best as possible from quality studies in the literature, but not all cost, utility, and transition probability estimates were supported by strong evidence. In several cases, expert opinion was used to make assumptions for the model. The experts were surveyed independently about probabilities of certain clinical outcomes, and then a consensus decision combining these individual estimates was made. The largest challenge in creating a credible model was to define HRQoL states for ARCR and RTSA because the 2 procedures' respective literature has traditionally studied disparate patient samples, primarily with respect to age and sex. In the face of this challenge, we chose to assume that HRQoL was equal after ARCR and RTSA for the base case, and we reported a 2-way sensitivity analysis that we hope will be useful as outcomes for more comparable cohorts after ARCR and RTSA are illuminated by future research. Recent literature shows that complication rates after RTSA may be expected to decrease, and there are inconsistent reports about the influence of a potential learning-curve.[58,59] In this study, it was assumed that patients with primary and secondary RTSA exhibited the same quality of life and surgical complication probabilities with evidence derived from the work of Mulieri et al.[28] Since Boileau et al.[60] suggested that secondary RTSA may be associated with inferior outcomes than primary RTSA, our assumption may make secondary RTSA disproportionally favorable. However, Boileau et al.'s results do not necessarily apply for the case of PP without OA. Furthermore, other authors have found no impact of previous cuff repair on the outcome of RTSA.[61] If, in the future, longer-term outcomes after either ARCR or RTSA are shown to provide better and more durable results, then another analysis will need to be done to assess the most cost-effective treatment paradigm at that time. Technical improvements in ARCR and RTSA that affect durability and survivorship also will affect the outcomes that this model predicted. Lastly, expected cost, HRQoL, and complication probabilities were assumed to be the same within each health state independent of patient age.

Conclusions

Primary ARCR with conversion to RTSA on potential failure was found to be the most cost-effective strategy for PP without OA. This result was independent of age. Primary ARCR with revision ARCR on potential failure was a less cost-effective strategy.

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