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ORIGINAL ARTICLE

Prospective Study

Reverse-total shoulder arthroplasty cost-effectiveness: A quality-adjusted life years comparison with total hip arthroplasty

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Clinical trial registration statement: Data used in this study was obtained from clinical trial PS-901.

Informed consent statement: All study participants provided written consent prior to study enrollment.

Conflict-of-interest statement: Dr. Ryan Krupp has served as a past consultant for DJO Surgical previously receiving an honorarium for teaching and also for research support. Drs. Bachman and Nyland have no conflicts of interest to disclose.

Data sharing statement: There is no additional data available.

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Abstract

AIM: To compare reverse-total shoulder arthroplasty (RSA) cost-effectiveness with total hip arthroplasty cost-effectiveness.

METHODS: This study used a stochastic model and decision-making algorithm to compare the cost-effectiveness of RSA and total hip arthroplasty. Fifteen patients underwent pre-operative, and 3, 6, and 12 mo post-operative clinical examinations and Short Form-36 Health Survey completion. Short form-36 Health Survey subscale scores were converted to EuroQual Group Five Dimension Health Outcome scores and compared with historical data from age-matched patients who had undergone total hip arthroplasty. Quality-adjusted life year (QALY) improvements based on life expectancies were calculated.

RESULTS: The cost/QALY was $3900 for total hip arthroplasty and $11100 for RSA. After adjusting the model to only include shoulder-specific physical function subscale items, the RSA QALY improved to 2.8

years, and its cost/QALY decreased to $8100.

CONCLUSION: Based on industry accepted standards, cost/QALY estimates supported both RSA and total hip arthroplasty cost-effectiveness. Although total hip arthroplasty remains the quality of life improvement "gold standard" among arthroplasty procedures, cost/QALY estimates identified in this study support the growing use of RSA to improve patient quality of life.

Key words: Quality of life; Arthroplasty; Shoulder; Cost-analysis

Core tip: Based on industry accepted standards, cost/quality-adjusted life year (QALY) estimates supported both reverse-total shoulder arthroplasty (RSA) and total hip arthroplasty cost-effectiveness. The cost/QALY estimates identified in this study support the growing use of RSA to improve patient quality of life.

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INTRODUCTION

The biomechanical advantage provided by improved deltoid muscle function following reverse-total shoulder arthroplasty (RSA) has led to its increased use for treating patients with massive rotator cuff tear arthropathy, severe shoulder fracture or gleno-humeral joint degeneration. Associated with this increased use is the need to better identify RSA cost-effectiveness with consideration for revision challenges[1], and its true utility in the context of diminishing healthcare financial resources[2]. History has demonstrated that total hip and knee arthroplasty use has progressively increased among patients with widely-ranging ages and diagnoses[3,4]. If patient outcomes prove comparable to these other arthroplasty procedures a similar evolution may develop for RSA.

The cost-effectiveness of RSA in terms of quality-adjusted life years (QALY) within the context of healthcare industry standards is currently unknown[5]. The purpose of this study was to compare RSA cost-effectiveness with total hip arthroplasty cost-effectiveness, widely considered to be the "gold standard" among arthroplasty procedures[6]. The study hypothesis was that both procedures would prove cost effective based on industry accepted standards of a $30000-50000 dollars United States/QALY[1-4]. Information such as this would provide vital insight into the true efficacy of RSA.

MATERIALS AND METHODS

Following University of Louisville and Norton Healthcare Medical Institutional Review Board approvals, 15 consecutive patients preparing to undergo RSA underwent pre-operative clinical examination by the same fellowship-trained shoulder surgeon. All patients had severe rotator cuff arthropathy. Given the lack of functional rotator cuff tissue an RSA was selected rather than a standard total shoulder arthroplasty. By reversing humeral head and glenoid component locations, RSA increased deltoid muscle mechanical efficiency during shoulder elevation and improved joint stability. All patients received a Donjoy Orthopaedic Reverse Shoulder Prosthesis (DJO, Vista, CA, United States). Patients also completed the short form-36 Health Survey subscales [physical function (PF), role physical (RP), role emotional (RE), bodily pain (BP), general health (GH), vitality (VT), mental health (MH), and social function (SF)]. Clinical examination and short form-36 surveys were repeated at 3-mo, 6-mo, and at 1-year post-surgery. By the end of the first post-operative year all patients were satisfied with the RSA procedure and had met their pain reduction and functional restoration expectations. These data were compared with the findings of Mangione *et al*[7] who studied 224 patients of similar age following total hip arthroplasty over the same follow-up time intervals, also collecting 0-100 point scale short form-36 survey data. Short form-36 subscale data from both studies was converted to EuroQual Group Five Dimension Health Outcome Scores using previously reported methods[8] and the following formula ($\alpha \times$ PF + $\beta \times$ RP + $\gamma \times$ RE + $\delta \times$ BP + $\varepsilon \times$ GH + $\zeta \times$ VT + $\eta \times$ MH + $\theta \times$ SF). In this formula the Greek letters signify constants from an accepted conversion algorithm[8]. Short form-36 physical function subscale score values for each follow-up time period were converted to QALY values[8]. Baseline values were then subtracted from follow-up QALY scores to identify condition improvements over time (1, 6 and 12 mo). This accounted for the entire first post-surgical year. For study purposes a 12 mo follow-up period was considered representative of peak quality of life improvement following arthroplasty[9,10].

A stochastic model and decision making algorithm[11,12] (Figure 1) incorporated revision rates[13,14] and a standard annual general health reduction to incrementally estimate QALY changes from baseline for each arthroplasty procedure simulating aging over the course of life expectancy[12]. The expected revision rate for each procedure (revisions/patient years followed) was applied to the stochastic model (Ω1, Ω2). Patient revisions/patient years was determined by taking the estimated number of procedural revisions divided by the number of patient follow-up years for total hip[13] and RSA[14]. For the duration of stochastic model application, for a projected revision, then the remainder of projected quality of life was considered to be only 50% improved from baseline state. If the patient required revision surgery 50% of their QALY potential was decreased

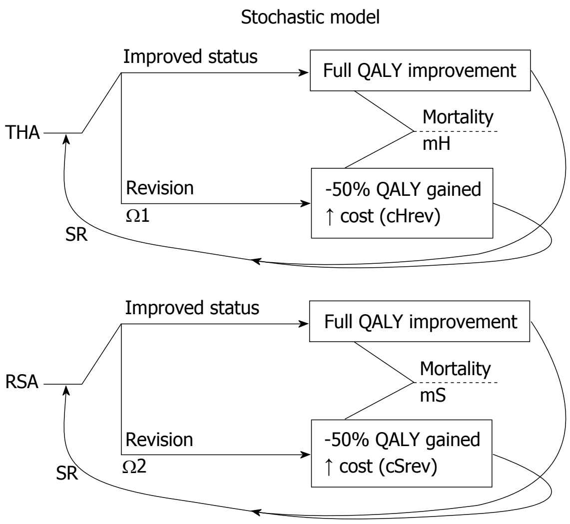

Figure 1 Stochastic model and decision-making algorithm. RSA: Reverse-total shoulder arthroplasty; QALY: Quality-adjusted life year; THA: Total hip arthroplasty; SR: Standard reduction in quality of life.

from that point forward[15]. A 3% annual general health decline representative of aging was also added to the model[16]. Annual quality of life improvement represented the previous year's quality of life improvement over baseline minus revision rate and standard general health reduction (3%). Collective quality of life improvement over baseline values were summed for the years of projected life for each arthroplasty group. This represented the QALY associated with each arthroplasty procedure.

Stochastic model variable definitions are provided in Table 1. Pre- (Hpreop, Rpreop) and post-operative (Ipostop) costs for each arthroplasty method including implant costs and hospital associated direct costs were determined using previously reported data[9] and data obtained from the hospital where the surgical procedure was performed. The same preoperative assessments were assumed for both arthroplasty surgical groups[9]. The average cost of a revision (Hrev or Rrev) was calculated by summing the non-implant related surgical and hospital costs (Hsurg or Rsurg), and the cost of the revised implant components (Hrevimplant or Rrevimplant), based on historical data[13,14] and post-operative cost estimates[15]. Revision costs calculated by the model represented the proportion of patients expected to undergo a revision multiplied by the average cost of a revision (either Hrev or Rrev). Revision expenses were then added to the primary cost. Cost per QALY were then calculated for each procedure.

Further evaluation was performed to determine the influence of short form-36 Health Survey subscale scores on the QALY of patients following total hip arthroplasty and RSA. Similar to the report of March *et al*[17], pain, physical function, and role-physical subscale scores displayed the greatest influence on QALY score improvement following either surgical procedure. The strongest single influence on QALY score improvement for both total hip arthroplasty and RSA was the physical function subscale. Focused attention to this subscale revealed that of 10 total items, nine related more specifically to ambulation while only three related more specifically to shoulder function. These included item 3a moderate activities such as moving a table, pushing a vacuum cleaner, bowling, or playing golf; item 3c lifting or carrying groceries; and item 3j bathing or dressing yourself[18]. The stochastic model was used to calculate QALY using both aggregate physical function subscale scores and scores based solely on the three more shoulder-specific physical function subscale question items.

RESULTS

Estimated QALY values were 2.0 years for RSA and 3.5 years for total hip arthroplasty. When the stochastic model and decision-making algorithm was applied without standard reductions for revision rates QALY values improved to 2.8 years for RSA and to 4.7 years for total hip arthroplasty. Total direct and indirect hospital cost estimates were $17000 for RSA and $11700 for total hip arthroplasty. Costs increased to $22200 and $13800, respectively, when adjusted for revision. Using these calculations the cost/QALY was $11100 for RSA and $3900 for total hip arthroplasty. Primary and revision implant costs represented 58% of RSA and 43% of total hip arthroplasty costs.

Short form-36 Health Survey physical function subscale scores initially revealed a considerable QALY value disparity between RSA and total hip arthroplasty patient groups. However, when including only shoulder-specific short form-36 physical function questions RSA QALY scores improved from 2.0 to 2.8 (t-test, P = 0.01) and RSA cost/QALY decreased to $8100.

DISCUSSION

The most important study finding is that the cost/QALY score for RSA is considerably less than the industry accepted standard of $30000-50000 cost/QALY[1-4]. Since only 3 of 10 (30%) short form-36 physical function subscale questions are specific to upper extremity function; this subscale is naturally skewed toward a hip and locomotion focus. When considering solely more shoulder-specific physical function subscale items the RSA QALY score improved significantly and shoulder region-specific estimate validity also improved.

Using a similar stochastic model and decision-making algorithm, Coe *et al*[5] reported than an implant cost less than $7000 United States dollars would make the RSA slightly more efficacious than shoulder hemiarthroplasty. In our study, total hip arthroplasty was approximately 2-3 times more cost effective than RSA. This finding however, does not preclude RSA cost effectiveness based on current industry accepted standards[1-4]. In a prospective study of 55 patients who were 70.8 (range = 46-88 years) years of age at time of RSA, Virani *et al*[2] reported that at a mean 48 mo

Table 1 Markov stochastic model

Component	Abbreviation	Value
Age of THA patients, yr ± SD[7]	AgeH	67.9 ± 9.0
Gender of THA patients, % men, % women[7]	%H-M, %H-W	46%, 54%
Age of RSA patient, yr ± SD	AgeS	69.3 ± 7.7
Gender of reverse shoulder patients, % men, % women	%RSM, %RSW	60%, 40%
Standard reduction in quality of life[9]	SR	-3%
[1]Pre-operative THA cost, $[7]	Hpreop	400
Pre-operative RSA cost, $[2]	Rpreop	600
[1]Cost of THA implant, $	Himplant	4300
[1]THA surgical and hospital costs, $	Hsurg	5600
[1]Total direct cost of THA, $	dcTHA	Himplant + Hsurg = 9900
[1]Cost of post-operative implant care, $[7]	Ipostop	1400
[1]Cost of primary THA, $	cTHA	dcTHA + Hpreop + Ipostop = 11700
Cost of THA revision implant, $[13]	Hrevimplant	%cup × cCup + %liner × cLiner + %stem × cStem = 1700
Average cost of THA revision, $[13]	Hrev	Hsurg + Hrevimplant = 7300
[1]Cost of RSA implant, $	Rimplant	8900
[1]RSA surgical, hospital costs, $	Rsurg	6100
[1]Total direct primary RSA cost, $	dcRSA	Rimplant + Rsurg = 15000
[1]Primary RSA cost, $	cRSA	dcRSA + Rpreop + Ipostop = 17000
[1]RSA revision implant cost, $	Revimplant	%glenoid × cGS + %Stem × cStem + %poly × cPoly %Hemi × cHemi = 4000
[1]Average revision RSA cost, $	Rrev	Rsurg + Revimplant
The length of first, second, third cycles hip, yr	hCL1, hCL2, hCL3	0.083, 0.416, 0.5
The length of first, second, third cycles shoulder, yr	sCL1, sCL2, sCL3	0.25, 0.25, 0.5
Length of cycle thereafter both, yr	CL	1
Age-specific mortality rate male, female[12]	mAgeM, AgeF	2007 United States life tables
Mortality rate, shoulder	mS	mAgeM × %SM + mAgeF × %SF
Mortality rate, hip	mH	mAgeM × %HM + mAgeF × %HF
THA revision cases[13]	hRev	44
Published cases[13]	hPC	211
THA follow-up years[13]	hFY	13.9 × hPC = 2932
Probability of THA revision/shoulder, yr	Ω1	hRev/hFY = 0.015
RSA revisions[14]	sRev	79
Published cases[14]	sPC	782
RSA follow-up years[14]	sFY	3.5 × sPC = 2737
RSA revision probability per shoulder, yr	Ω2	sRev/sFY = 0.029
Utility, quality of llfe improvement, EQ-5D	pQoL, oQoL	α × PF + β × RP + γ × RE + δ × BP + ε × GH + ζ × VT + η × MH + θ × SF
Utility hip, shoulder	qHwell, qSwell	oQOL - pQOL
The utility associated with a THA revision, QALY	qHrev	0.5 × qHwell
The utility associated with a RSA revision, QALY	qSrev	0.5 × qSwell

[1]Norton Healthcare cost data Louisville, KY, United States. RSA: Reverse-total shoulder arthroplasty; QALY: Quality-adjusted life year; THA: Total hip arthroplasty; PF: Physical function; RP: Role physical; RE: Role emotional; BP: Bodily pain; GH: General health; VT: Vitality; MH: Mental health; SF: Social function; oQOL: Post-operative quality of life; pQOL: Pre-operative quality of life.

follow-up patients had an 82% shoulder pain reduction and a 70% shoulder function improvement. This study estimated a mean 4-year total cost of $24661, with hospitalization accounting for 92% of the total cost[2]. These findings suggest the need for an earlier transition to a less expensive outpatient care environment as an important step in managing post-RSA costs.

Study limitations

The small sample size of this study necessitated several stochastic modeling assumptions. With the development of more shoulder-specific quality of life measurement tools and additional long-term RSA revision rate data, cost effectiveness estimates will become more accurate[5]. Regardless, identical analytical procedures were performed for both arthroplasty patient groups generating valid, cost/QALY estimates. Since patient outcomes, hospitalization timetables, and implant costs may be influenced by multiple factors including regional differences, patient age and comorbidities, rehabilitation strategies and activity expectations, clinicians are advised to use care when extrapolating these data to individual practice sites.

Conclusion

Based on industry accepted standards, cost/QALY estimates supported both RSA and total hip arthroplasty cost-effectiveness. Although total hip arthroplasty remains the quality of life improvement "gold standard" among arthroplasty procedures, cost/QALY estimates identified in this study support the growing use of RSA to improve patient quality of life.

COMMENTS

Background

Comparing the reverse-total shoulder arthroplasty (RSA) with the "gold standard" arthroplasty procedure was a daunting task.

Research frontiers
The results of this study confirm the efficacy of RSA for positively impacting patient quality of life.

Innovations and breakthroughs
Since hospitalization accounted for a high percentage of the total cost, future studies should investigate the efficacy of making an earlier transition to a less expensive outpatient care environment.

Peer-review
This is a nice paper.

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