Cost-Effectiveness Analysis Comparing Proximal Row Carpectomy and Four-Corner Arthrodesis

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Background: The optimal surgical treatment for scapholunate advanced collapse (SLAC) and scaphoid nonunion advanced collapse (SNAC) remains unclear. To inform clinical decision-makers, we conducted a cost-effectiveness analysis comparing proximal row carpectomy (PRC) and four-corner arthrodesis (FCA).

Methods: A Markov microsimulation model was used to compare clinical outcomes, costs, and health utilities between PRC and FCA. The model used a 10-year time horizon and a 1-month cycle length, and it was evaluated from the societal perspective. Utilities and clinical parameters including transition probabilities for debridement for infection, removal of implants, conversion to total wrist arthrodesis, revision FCA, and revision total wrist arthrodesis were obtained from published literature. Timing of complications was estimated from the literature. Direct medical costs were derived from Medicare ambulatory surgical cost data, and indirect costs for missed work due to surgical procedures and complications were included. The effectiveness outcome was quality-adjusted life years (QALYs). Probabilistic sensitivity analysis and 1-way threshold analysis for utilities were performed.

Results: In the base-case model, PRC dominated FCA (i.e., PRC had lower cost and greater effectiveness). The mean (and standard deviation) for the total cost and QALYs per patient were $30,970 ± $5,931 and 8.24 ± 1.28, respectively, for PRC and $44,526 ± $11,205 and 8.23 ± 1.26, respectively, for FCA. In the probabilistic sensitivity analysis, PRC dominated FCA in 57% of the 1 million iterations. The cost-effectiveness acceptability curve indicated that PRC is the most cost-effective strategy regardless of the willingness-to-pay threshold up to $100,000/QALY.

Conclusions: PRC dominated FCA in the base-case analysis and in the probabilistic sensitivity analysis. These results suggest that PRC is the optimal strategy for Stage-I or II SLAC and for SNAC in patients ≥55 years of age.

Level of Evidence: Economic <u>Level IV</u>. See Instructions for Authors for a complete description of levels of evidence.

E mphasis on health-care costs has grown over the past decade in the U.S., in part because of policy changes that have included value-based payment models[1,2]. For patients with Stage-I or II scapholunate advanced collapse (SLAC) or scaphoid nonunion advanced collapse (SNAC) arthritis for whom motion-sparing surgery is indicated, the optimal treatment remains unclear[3] and has traditionally included either proximal row carpectomy (PRC) or four-corner arthrodesis (FCA)[4,5]. Because SLAC arthritis is the most common form of wrist degenerative arthritis[6], defining the optimal surgical treatment would be an important step in improving patient outcomes while minimizing costs.

Clinical outcomes, or health states or utilities, are integral in determining the cost-effectiveness of a given treatment. Numerous studies have assessed the clinical outcomes of PRC and FCA[3,6-22]. Two systematic reviews of PRC and FCA outcomes did not identify any differences in patient-reported disability, subjective ratings of satisfaction, rate of conversion to total wrist arthrodesis, or increase in grip strength[7,8]. Despite these findings and reports that both PRC and FCA can be associated with the development of radiographic evidence of arthrosis at long-term follow-up[6,23], some authors have stated that FCA may provide a more desirable result[6,24-27]. It is clear that

controversy exists with regard to which surgery yields a superior clinical result.

Literature related to the direct and indirect costs of PRC and FCA is limited. In one report, the surgical encounter direct costs for FCA were 425% greater than those for PRC[28]. Similarly, a large database study indicated that cumulative surgical costs for PRC were significantly less than those for FCA ($7,171 versus $10,842) when postoperative costs of complications were included[29].

Despite this prior literature, the optimal surgical treatment for patients with Stage-I or II SLAC or SNAC remains in question. The purpose of this study was to perform a cost-effectiveness analysis comparing PRC with FCA using a Markov microsimulation model from the societal perspective to determine the optimal treatment strategy.

Materials and Methods

Overview

This cost-effectiveness analysis was performed in accordance with the recommendations of the Second Panel on Cost-Effectiveness in Health and Medicine[30]. We used a Markov simulation model to estimate the effectiveness and cost-effectiveness of PRC and FCA in patients with SLAC or SNAC wrist arthritis[31-33]. The model, which had a cycle length (period of time in which patients may transition from one health state to another, or remain in the same health state) of 1 month, was evaluated from a societal perspective over a 10-year time horizon in a modeled population of 10,000 hypothetical 55-year-old patients. A 10-year time horizon was chosen because robust clinical postoperative data are lacking beyond this time frame in the literature, which precludes accurate calculation of long-term complication probabilities[29,34]. Both treatments were evaluated with

respect to both effectiveness and cost. The effectiveness measure was quality-adjusted life years (QALYs), which encompass both duration and quality of life. Costs included those related to surgical treatment and associated care as well as indirect costs for each patient from the time of the initiation of treatment until death or the end of the 10-year time horizon (whichever occurred first).

Model Structure

Figure 1-A depicts the Markov model structure. Patients were assigned a probability of survival status based on average mortality rates provided by the U.S. Social Security Administration in 2015[35]. Patients who underwent FCA or total wrist arthrodesis had the potential to experience nonunion, which could lead to revision surgery. In addition, each surviving patient could experience adverse events associated with their treatment as depicted in Figure 1-B. Adverse-event probabilities were estimated from weighted averages of values reported in published clinical reports (Table I). Outcomes from the model included costs and QALYs. Both costs and utilities were discounted 3% annually. The model was programmed in TreeAge Pro 2018 (TreeAge Software).

Input Parameters

A PubMed and Google Scholar search was performed using the keywords "four corner arthrodesis," "proximal row carpectomy," "total wrist arthrodesis," "SLAC" or "scapholunate advanced collapse," and "SNAC" or "scaphoid nonunion advanced collapse." An additional query using the term "fusion" in place of "arthrodesis" was also performed, as applicable. Articles were reviewed, and those involving index surgical procedures for treatment of other disease processes and those that did not report rates of complications or return to work were excluded. Complication rates,
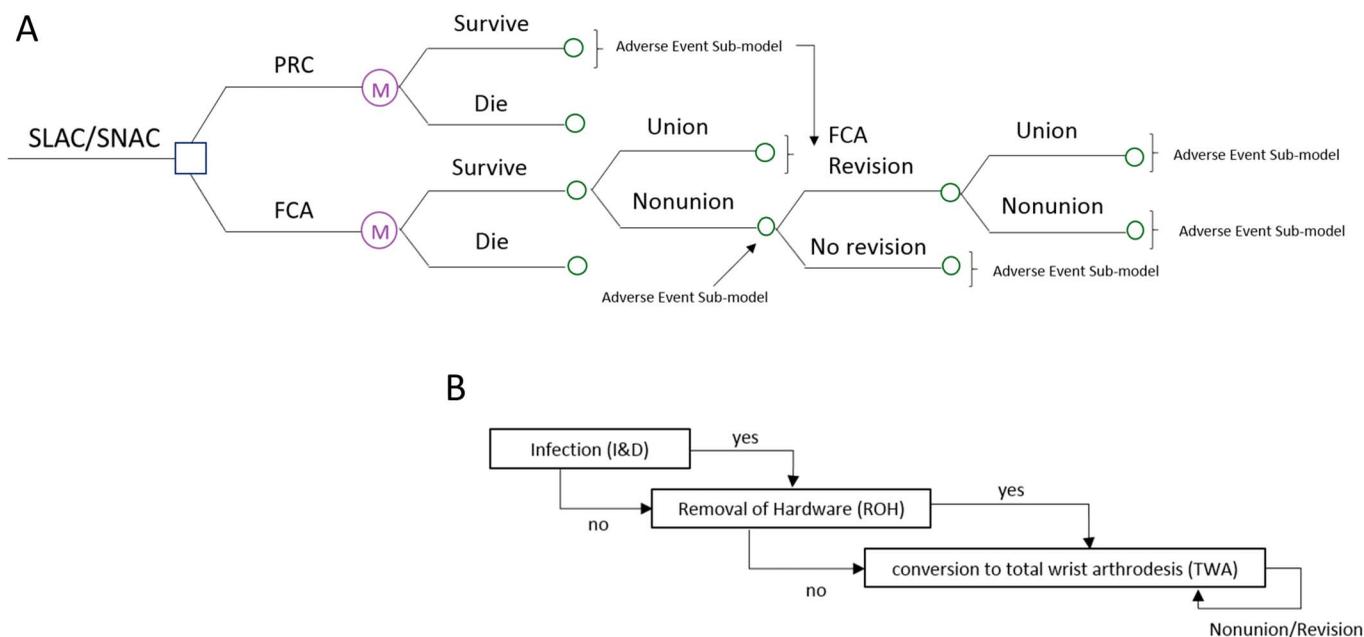

Fig. 1

Illustration of the structure of the Markov model (**Fig. 1-A**) and the adverse event submodel (**Fig. 1-B**). I&D = irrigation and debridement. The circled "M" refers to "Markov node," which signifies that the cycle repeats itself (in this case, the cycle repeats itself monthly for the duration of the simulation period of 10 years).

TABLE I Cost and Probability Input Data for the Markov Model			
Event	Value	SD	Source
Lifetime probabilities			
PRC*			
Infection requiring irrigation and debridement	0.30%	0.50%	Literature[3,18,33,34,36]
Removal of implants	0.00%	0.00%	Literature[29,34]
Total wrist arthrodesis	6.20%	4.90%	Literature[3,9,18,22,23,29,34,36-39]
Nonunion/total wrist arthrodesis revision†	5.00%	4.00%	Literature[41-45,53]
FCA			
Infection requiring irrigation and debridement	2.20%	4.30%	Literature[3,18,34,36]
Removal of implants	34.30%	12.60%	Literature[27,29,34,53,54]
Total wrist arthrodesis	16.80%	5.80%	Literature[3,9,18,19,22,27,29,34,36-38]
Nonunion‡	12.90%	10.10%	Literature[19,36]
Revision FCA	4.60%	1.20%	Literature[9,18,27,29,36]
Nonunion/total wrist arthrodesis revision†	5.00%	4.00%	Literature[41-45,53]
Costs			
Surgical			
PRC	$7,069	$3158	Medicare[46,47]
FCA	$12,119	$7198	Medicare[46,47]
FCA revision	$12,119	$7198	Medicare[46,47]
Infection requiring irrigation and debridement	$7,068	$3519	Medicare[46,47]
Removal of implants	$6,840	$3575	Medicare[46,47]
Total wrist arthrodesis	$8,893	$5469	Medicare[46,47]
Total wrist arthrodesis revision	$8,893	$5469	Medicare[46,47]
Indirect costs			
Average median weekly earnings in 2013	$776.5	—	Bureau of Labor Statistics[48]
Labor force rate (2013)	60.4%	—	Bureau of Labor Statistics[55] §
PRC			
Missed days of work	$10,095 (3 mo)	—	Literature[13,36]/Bureau of Labor Statistics[48]
Rate of return to work	92.4% ($256/mo)	—	Literature[3,9,11,13,15,19,23,37]
FCA			
Missed days of work	$10,095 (3 mo)	—	Literature[13,36]/Bureau of Labor Statistics[48]
Rate of return to work	90.8% ($310/mo)	—	Literature[3,9,13,15,19,27,53]
Irrigation and debridement			
Missed days of work	$1,553 (2 wk)	—	Expert opinion/Bureau of Labor Statistics[48]
Removal of implants			
Missed days of work	$1,553 (2 wk)	—	Expert opinion/Bureau of Labor Statistics[48]
Total wrist arthrodesis			
Missed days of work	$9,303(12.0 ± 2.7 wk)	—	Literature[40-45,56]/Bureau of Labor Statistics[48]
Rate of return to work	85.0% ($506/mo)	—	Literature[40-44,56]

*No references describing revision PRC were identified; therefore, this potential scenario was not included as a possible complication. †This refers to the scenario of nonunion after total wrist arthrodesis for which a revision total wrist arthrodesis is performed. ‡This refers to nonunion after an index FCA. §The data were acquired by choosing the "Labor force" link followed by a customized search with the following parameters: both sexes, all races, all Hispanic or Latino or other origins, age 55 to 64 years, all education levels, all marital statuses, and civilian labor force participation rate for "labor force status."

reoperation rates, and rates of conversion to total wrist arthrodesis were extracted from the remaining articles. Articles that included appropriate data were reviewed for bibliographic citations related to the above keywords in a secondary search for complication and return-to-work rates. Data from 11 reports were used to define complication rates for PRC[3,9,18,22,23,29,34,36-39], and 17 were used for FCA complication rates[3,9,18,19,22,27,29,34,36-38,40-45] (Table I). One of these sources was a published abstract that contained data on the timing of complications following the index surgical procedures[34]. Weighted averages and standard deviations (SDs) were calculated for the following complications of PRC and FCA: infection requiring irrigation and debridement, removal of implants, revision, conversion to total wrist arthrodesis, nonunion after FCA, and revision after FCA (Table I). Weighted averages and SDs were calculated for revision total wrist arthrodesis, missed days of work, and likelihood of returning to any form of work following PRC, FCA, and total wrist arthrodesis. Given a lack of available data, we assumed that the rates of return to work following revision FCA or revision total wrist arthrodesis were identical to those following their respective index procedures.

Kaplan-Meier data from a study utilizing national Veterans Health Administration (VHA) Corporate Data Warehouse (CDW) data were used to populate the model with input parameters describing the timing of specific complications following PRC and FCA (Table II)[34]. The timing of total wrist arthrodesis following index PRC and FCA and the timing of other complications requiring surgery (irrigation and debridement, removal of implants, or revision FCA) were derived from this report or from the expert opinion of 2 board-certified hand orthopaedic surgeons for missing parameters. These input parameters describing the timing of complications were then assessed using sensitivity analysis.

We assumed that irrigation and debridement for infection would not occur beyond 3 months following the index surgical procedures. We also assumed that revision FCA or revision total wrist arthrodesis due to total wrist arthrodesis nonunion would not occur until 6 months following the index surgery, to allow for a period of waiting for union to occur, and not beyond 12 months following the index surgery. Patients could not have multiple instances of the same complication (irrigation and debridement or removal of implants) following the index surgery or following revision FCA. A single surgical revision was possible following the index FCA and for nonunion after total wrist arthrodesis. The model did not allow for revision PRC given the absence of published rates of this potential complication. We also assumed that no patient had removal of implants following PRC.

Costs

Costs related to ambulatory index surgical procedures and for surgical procedures related to complications were calculated as the sum of Medicare surgeon, anesthesia, and facility payments obtained through a query of respective Current Procedural Terminology (CPT) codes (see Appendix 1). Average 2016 Medicare standardized payments were used for surgeon costs[46], and ambulatory facility and anesthesia costs were obtained from the 2013 Florida State Ambulatory Surgery and Services Database (SASD)[47]. Surgical procedures and anesthesia services were identified by CPT code. For surgical procedures with >1 applicable CPT code, weighted averages for surgeon and facility costs were calculated and used in the model. Indirect costs were also included in the total cost of surgical procedures and complications, and were calculated as loss of income from estimates of missed work and the likelihood of returning to any form of work following surgical procedures as determined from published data or expert opinion (Table I). These estimates were multiplied by the average median earnings reported by the U.S. Bureau of Labor Statistics (BLS) for full-time wage and salary workers ($776.50/week in 2013 U.S. dollars)[48]. Total indirect costs of missed days of work or those associated with each surgical procedure/complication were added at the time of occurrence, taking into consideration BLS estimates of the percentage of patients in the work force by age. Monthly indirect costs of

TABLE II Time Frame for Adverse Event Input Data for the Markov Model		
	Time Frame *(mo)*	Source*
PRC		
Infection requiring irrigation and debridement	0-3	Expert opinion
Total wrist arthrodesis	6-232	VHA CDW[34]
Total wrist arthrodesis nonunion	0-3	Expert opinion
FCA		
Infection requiring irrigation and debridement	0-3	Expert opinion
Removal of implants	3-137	VHA CDW[34]
Total wrist arthrodesis	6-162	VHA CDW[34]
FCA revision	6-12	Expert opinion
FCA nonunion	6-12	Expert opinion
Total wrist arthrodesis nonunion	6-12	Expert opinion
*VHA CDW = Veterans Health Administration Corporate Data Warehouse.		

TABLE III Annual Utility Input Data for the Markov Model		
Utility/Disutility	Utility/Disutility Value	Source
Utility for healthy state		
PRC	0.99	Literature[49]
FCA	0.99	Literature[49]
Disutility for PRC		
Infection requiring irrigation and debridement	−0.002	Literature[49]
Total wrist arthrodesis/total wrist arthrodesis revision	−0.02	Expert opinion/literature[49]
Total wrist arthrodesis nonunion	−0.002	Expert opinion/literature[49]
Disutility for FCA		
Infection requiring irrigation and debridement	−0.008	Literature[49]
Removal of implants	−0.008	Literature[49]
Total wrist arthrodesis/total wrist arthrodesis revision	−0.02	Expert opinion/literature[49]
Total wrist arthrodesis nonunion	−0.008	Expert opinion/literature[49]
FCA revision	−0.03	Expert opinion/literature[49]
FCA nonunion	−0.006	Expert opinion/literature[49]

unemployment were added every month after the event happened until death or the end of the study cycle, whichever occurred first, since the remaining years differed from subject to subject in the model. We assumed that the surgical encounter costs for a revision of an FCA or a total wrist arthrodesis were the same as those for an initial FCA or total wrist arthrodesis, as revision-specific CPT codes do not exist. All costs were adjusted to 2013 U.S. dollars using the Personal Consumption Expenditures price index for health-care services. Due to a lack of values in the literature, we assumed that patients would be out of work for 2 weeks following irrigation and debridement or removal of implants. We also assumed that the time off from work would be equivalent for revision and index FCA and be equivalent for revision total wrist arthrodesis and total wrist arthrodesis.

Utilities
Effectiveness was measured in QALYs. Utility was measured on a scale on which 1.0 represented a state of perfect health and 0.0 represented death. Utility estimates for PRC and FCA with and without complications, and disutility of complications including total wrist arthrodesis, were obtained from a published study (Table III)[49]. The disutility of nonunion or revision following total wrist arthrodesis and the disutility of nonunion or revision following FCA were determined using these previously published utilities and by expert opinion. The disutility of irrigation and debridement or removal of implants was subtracted from the baseline

utility at the time at which a patient underwent the procedure; this disutility persisted for 1 cycle (1 month), after which the pre-complication utility was reapplied. The disutility of total wrist arthrodesis, nonunion following total wrist arthrodesis, or a second FCA nonunion were permanently deducted from the premorbid utility.

Mortality
The mortality rate was obtained from the 2015 Social Security Area Population Life Tables and averaged between sexes[35]. An age-dependent mortality rate was applied in an identical manner for FCA and PRC, and it was not modified based on a subject experiencing a postoperative complication.

Sensitivity Analysis
One-way and probabilistic sensitivity analyses were performed as described in Appendix 2.

Results
Base Case
Base case analysis revealed 10-year mean total costs (and SDs) of $30,970 ± $5,931 for PRC and $44,526 ± $11,205 for FCA (Table IV). PRC yielded 8.24 ± 1.28 QALYs versus 8.23 ± 1.26 QALYs for FCA. Overall, PRC was $13,556 less costly and added 0.0104 QALY per patient compared with FCA. PRC was considered the dominant treatment strategy as it yielded lower costs and higher QALYs than FCA.

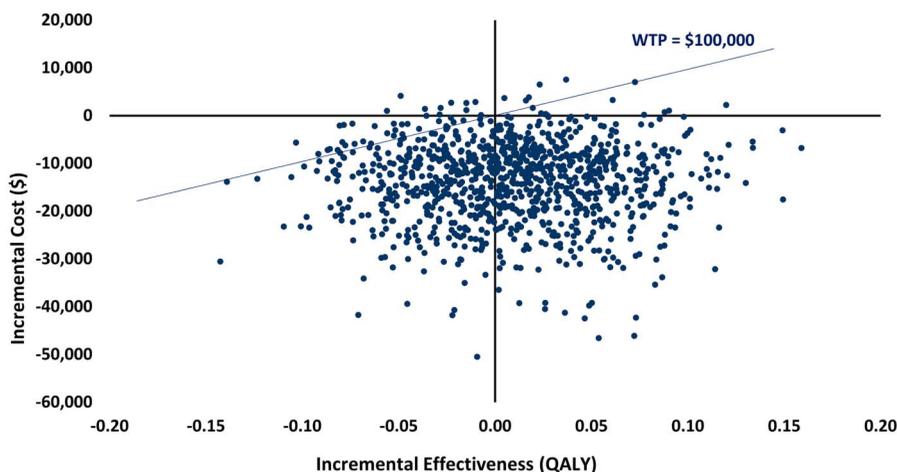| TABLE IV Cost-Effectiveness Analysis Results for Base Case					
Procedure	Mean Cost ± SD (2013$)	Incremental Cost (2013$)	Mean Effect ± SD (QALYs)	Incremental Effect (QALYs)	ICER ($/QALY)
PRC	$30,970 ± $5,931	$0	8.2412 ± 1.2771	0.0000	$0
FCA	$44,526 ± $11,205	$13,556	8.2308 ± 1.2594	−0.0104	−$1,301,322

Fig. 2

Scatterplot showing the distribution of incremental costs and incremental effectiveness of individual iterations of the probabilistic sensitivity analysis comparing the cost-effectiveness of PRC versus FCA for patients with SLAC or SNAC. The diagonal line represents a willingness-to-pay (WTP) threshold of $100,000 per QALY. Data points to the right and below this line indicate that PRC was considered cost-effective compared with FCA according to the WTP threshold.

Threshold Analysis on Utility Values

Threshold analyses demonstrated that our model was robust to utility or disutility parameter values (e.g., the conclusion was not reversed by changing these inputs over a wide range). The model switches from PRC being cost-effective to being not cost-effective at an incremental cost-effectiveness ratio (ICER) of $100,000/QALY if the utility of PRC is reduced to <0.97.

Probabilistic Sensitivity Analysis

Probabilistic sensitivity analysis demonstrated that PRC dominated FCA in 57% of the 1 million iterations (Fig. 2). At a willingness-to-pay threshold of $100,000/QALY, PRC was cost-effective compared with FCA in 61% of the iterations. The cost-effectiveness acceptability curve indicates that PRC was the most cost-effective strategy regardless of the willingness-to-pay threshold up to $100,000/QALY (Fig. 3).
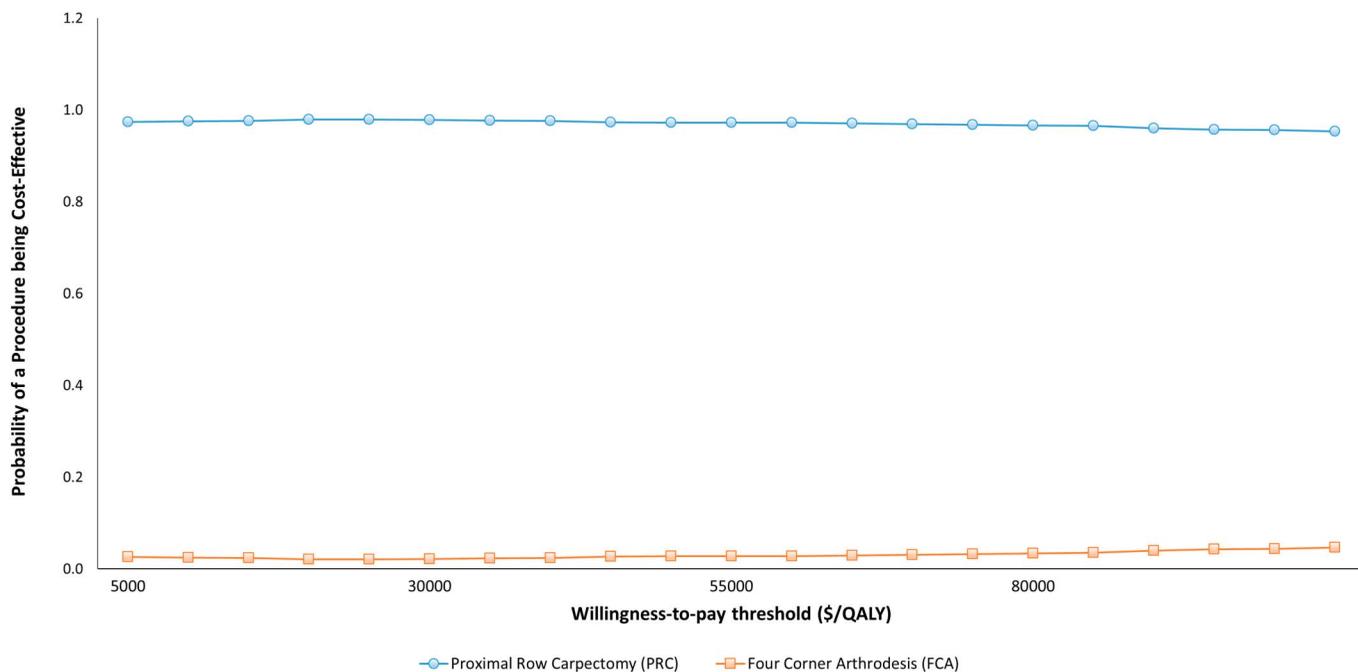

Fig. 3

Cost-effectiveness acceptability curve showing the change in the probability of cost-effectiveness of PRC and FCA treatment strategies over a range of willingness-to-pay threshold values.

Discussion

The main study finding was that PRC dominated FCA. In other words, PRC yielded better outcomes measured by QALYs and cost less than FCA. However, since the difference in QALYs was small, the main difference is decreased costs and rates of complications after PRC. Based on probabilistic sensitivity analysis, these findings were robust to variations in rates of complications or return to work as well as costs of index and subsequent surgical procedures. These findings were also robust to the utilities for PRC and FCA, as threshold sensitivity analysis demonstrated that the utility of PRC would have to drop from 0.99 to <0.97 in order to reverse this conclusion. Given the utility of 0.99 for FCA without complications, a utility of <0.97 for PRC without complications is unlikely given an abundance of research suggesting that the clinical outcomes of PRC and FCA are similar[7,8]. This utility threshold is also relatively low when considering that disutilities for complications following FCA are on the order of −0.006 for a nonunion to −0.02 for a total wrist arthrodesis[49]. Therefore, we conclude that PRC is the preferred treatment strategy for patients ≥55 years of age who have Stage-I or II SLAC or SNAC of the wrist.

Our findings differ slightly from a prior cost-effectiveness analysis by Daar et al., who concluded that FCA with successful screw fixation dominated PRC, FCA with plate fixation, and FCA with Kirschner-wire fixation[50]. Those authors also concluded that FCA with screw fixation and PRC were both cost-effective treatment strategies for SLAC and SNAC of the wrist, whereas the other 2 strategies were not cost-effective. However, their literature review was restricted to studies reporting FCA fixation types. This led to the exclusion of the article by Rahgozar et al.[29], who observed a significantly greater rate of conversion to total wrist arthrodesis after FCA than after PRC in a commercial database study that included more patients (3,388) than all of the clinical reports combined used in the current study to extract complication rates. Therefore, the majority of patients in the reported literature were excluded from the study by Daar et al., which would introduce a bias in favor of FCA over PRC. Additionally, utilities that were derived using hand surgeons' opinions in the study by Daar et al. warrant further evaluation. In contrast to published reports (including 2 systematic reviews[7,8]) suggesting no clinically relevant differences in functional outcomes between PRC and FCA[3,9,18], the utility that Daar et al. calculated for a successful FCA with screw fixation was greater than that for PRC (0.81 and 0.78, respectively). Also, the utilities for patients with complications following PRC or FCA—including those in the range of 0.50 to 0.53 for total wrist arthrodesis—may be unrealistically low compared with previously reported utilities for wrist arthritis surgical procedures and their sequelae (≥0.90)[49] and in light of published utilities in the range of 0.48 to 0.58 for end-stage congestive heart failure[51] and approximately 0.55 for metastatic lung cancer[52]. It is improbable that a wrist condition should yield a health state as low as that associated with terminal diseases.

Limitations of the current study deserve mention. The literature lacks comprehensive long-term comparative data on outcomes, complication rates, and rates of conversion to total wrist arthrodesis after PRC and FCA. As a result, we restricted our study to a 10-year time period. However, it is possible that the addition of long-term data, should it be published in the future, could affect our results. Although inclusion of complications data from a large commercial database study[29] provides information from thousands of patients potentially not included in other published clinical reports, our results may still be sensitive to publication bias—published results may not reflect the true results of PRC, FCA, or total wrist arthrodesis. The literature lacks granular detail on some of the model inputs such as the number of missed days of work following irrigation and debridement or removal of implants, and values assigned to these scenarios on the basis of expert opinion may be debatable. Although a prior comparison of PRC and FCA in young patients (<45 years old)[18] showed similar outcomes, it is unclear if our results could be generalized to young patients as most of our complication data were derived from patients ≥55 years of age. Although several methods for determining utilities have been described, we utilized previously published utilities that did not account for the potential for disutility during recovery from PRC, FCA, or total wrist arthrodesis[49]. Although the 1-way sensitivity analysis suggests that our findings are relatively robust to the index surgery utilities, it is possible that alternative methods for utility calculation could affect our results. The union rate for FCA differs according to the method of fixation, as highlighted by Daar et al.[50], and our analysis is limited in that it did not account for fixation type. Finally, there are limitations related to the costing methods used in this study. Indirect costs used for time off from work may differ for individual patients who do not work or those who have high levels of income. Although PRC yielded better utilities than FCA, the difference of 0.01 QALY between FCA and PRC is highly unlikely to be clinically relevant. Although we could not identify publications reporting rates of revision PRC, the true rate is unlikely to be 0% as assumed in this analysis; it is unclear if or how a small but non-zero rate may affect the results. Although commonly used, Medicare costs may not reflect costs of health care provided in systems with commercial or other payers and may be affected by coding errors. Similarly, we used Veterans Affairs (VA) data to describe the timing of complications; patients treated in the VA health system may differ from the general population.

PRC dominated FCA in the base-case analysis and in the probabilistic sensitivity analysis. These results suggest that PRC is the optimal strategy for Stage-I or II SLAC or SNAC of the wrist for patients who are ≥55 years of age.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A172). ■

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