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Original Research

A Cost-Effectiveness Analysis of the Various Treatment Options for Distal Radius Fractures

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Purpose: To conduct a cost-effectiveness study of nonsurgical and surgical treatment options for distal radius fractures using distinct posttreatment outcome patterns.
Methods: We created a decision tree to model the following treatment modalities for distal radius fractures: nonsurgical management, external fixation, percutaneous pinning, and plate fixation. Each node of the model was associated with specific costs in dollars, a utility adjustment (quality-adjusted life year [QALY]), and a percent likelihood. The nodes of the decision tree included uneventful healing, eventful healing and no further intervention, carpal tunnel syndrome, trigger finger, and tendon rupture as well as associated treatments for each event. The percent probabilities of each transition state, QALY values, and costs of intervention were gleaned from a systematic review. Rollback and incremental cost-effectiveness ratio analyses were conducted to identify optimal treatment strategies. Threshold values of $50,000/QALY and $100,000/QALY were used to distinguish the modalities in the incremental cost-effectiveness ratio analysis.
Results: Both the rollback analysis and the incremental cost-effectiveness ratio analysis revealed nonsurgical management as the predominant strategy when compared with the other operative modalities. Nonsurgical management dominated external fixation and plate fixation, although it was comparable with percutaneous fixation, yielding a $2,242 lesser cost and 0.017 lesser effectiveness.
Conclusions: The cost effectiveness of nonsurgical management is driven by its decreased cost to the health care system. Plate and external fixation have been shown to be both more expensive and less effective than other proposed treatments. Percutaneous pinning has demonstrated more favorable effectiveness in the literature than plate and external fixation and, thus, may be more cost effective in certain circumstances. Future studies may find value in investigating further clinical aspects of distal radius fractures and their association with nonsurgical management versus that with plate fixation.
Type of study/level of evidence: Economic/decision analysis II.

Introduction

Distal radius fractures (DRFs) are among the most common orthopedic injuries and account for an estimated $535 million in Medicare spending annually.[1,2] The expanding elderly population in the United States is expected to drive the growth of DRF spending and a 40% increase in DRF surgeries.[2] Considering the significant financial impact of DRFs, data regarding the cost effectiveness of available treatment options may help guide decision making for clinicians.

Distal radius fractures can be managed nonsurgically with closed reduction and cast immobilization or with surgical fixation

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techniques such as plate fixation, percutaneous pinning, or external fixation. The decision to pursue surgical versus nonsurgical treatment is based on fracture stability and displacement as well as patient-specific factors, including age, activity level, and patient preferences. The literature has offered varying conclusions on the indications and effectiveness of various methods for surgical fixation, resulting in high variability in management practices among geographic locations.[3,4] Plate fixation has become increasingly popular following the development of locking volar plates and offers substantial benefits, such as early mobility, but is expensive relative to other treatment options and may be associated with an increased surgical risk.[5] Percutaneous pinning is less invasive than plate fixation and may offer a lower cost burden for patients while demonstrating clinical effectiveness; however, it does not allow for early mobility, and some studies have cast doubt on its ability to adequately maintain reduction.[6−9] Finally, external fixation has demonstrated adequate reduction control over time while minimizing invasiveness; however, higher rates of complications, such as surgical-site infection and complex regional pain syndrome, have led to this technique largely falling out of favor.[10,11] In response to the ongoing debate surrounding DRF management, it is important to compare the effectiveness of these treatment modalities in light of their associated direct and indirect financial costs.

The cost-effectiveness analysis has undergone decades of development to emerge as a tool for evaluation of medical strategies by means of comparing incremental costs with health benefits.[12] In the cost-effectiveness analysis methodology, the cost is typically presented as dollars spent by either the health care system or the patient, whereas the effectiveness is measured using a combination of patient-reported values and successful surgical rates. In recent years, quality-adjusted life year (QALY) assessments, such as the EuroQol 5-D questionnaire, have emerged as the preferred measure of subjectively defined clinical effectiveness because they can provide an insight into the avoidance of symptoms and improvement in quality of life with different interventions.[12,13] With the complexity of symptoms, adverse events, and patient-reported effectiveness associated with DRF interventions, a detailed cost-effectiveness analysis would shed light on optimal treatments.

Our goal was to conduct a cost-effectiveness study using distinct posttreatment outcome patterns for the following DRF treatment modalities: nonsurgical management, external fixation, percutaneous pinning with K-wire, and plate fixation. Because of decreased associated costs and similar clinical effectiveness, we hypothesized that wire fixation would dominate as the most cost-effective treatment modality, as measured using dollars spent per QALY.[6,7]

Materials and Methods

Study design

This study was exempt from institutional review board approval. All analyses were conducted in accordance with Second Panel on Cost-Effectiveness in Health and Medicine guidelines using the TreeAge Pro software.[14,15] This study included a systematic review of the most reported complications and treatment pathways for DRFs. Primary research articles published between 2000 and 2020 involving participants aged 19 years or older and written in the English language were eligible for inclusion. Case reports, expert commentaries, and unpublished data were excluded. This study was conducted over a 1-year period. Importantly, this study did not attempt to stratify case results by age or severity of fracture because of limitations in the breadth of available literature. This notion is further explored in the limitations section.

Decision model

We created a decision tree to model the treatment of DRFs using nonsurgical management, external fixation, percutaneous pinning with K-wires, and plate fixation. Each node of the model was associated with specific costs in dollars, a utility adjustment (QALY), and a percent likelihood.

Event probabilities

After surgical or nonsurgical management of fractures, our model predicts the following possible outcomes: uneventful reduction or eventful reduction. Uneventful reduction corresponds to successful healing of the fracture, with no side effects or revisions warranted. Eventful reduction is a critical nodule that may lead to the following transition states: loss of reduction, carpal tunnel syndrome, tendon rupture, trigger finger, or a combination of minor complications. Each transitional state is accompanied thereafter by another decision matrix (treatment vs no treatment). Surgical modalities requiring implant or external fixation also included an implant removal transition state in all branches and were considered an operating room-related procedure for cost summation. Outcome probabilities, as gathered by the systematic review of the literature, were calculated for each modality. The query details of the systematic review can be seen in Appendix 1 (available on the *Journal*'s website at www.jhsgo.org). The exclusion criteria included research articles that lacked full texts, review articles, and case studies. Similarly, articles that included patients with osteoporosis or those without adequate postoperative documentation of treatment outcomes and adverse events were excluded. Further details of the exclusion criteria and the flow diagram of the data can be seen in Figure 1. This literature search resulted in 1,877 abstracts pertaining to outcomes in patients with DRFs. From these 1,877, only 101 articles remained for inclusion in our study. Of these 101 articles and 11,329 patients, 698 patients underwent nonsurgical management, 2,322 patients underwent external fixation, 411 patients underwent percutaneous pinning, and 7,898 patients underwent plate fixation. All transition-state probabilities and ranges can be seen in Table 1.[3,5,16,17−102]

Costs and utility estimation

The health care perspective represents the sum of health care center costs, physician fees, and anesthesia fees. The national average health care center costs and physician fees were calculated from the Current Procedural Terminology code total allowable reimbursement sourced from Centers for Medicare & Medicaid Services Physician Fee Schedule and Ambulatory Surgical Center Payment tools for the year 2020.[15,112] The anesthesia costs were calculated using surgical time data from the literature. The total allowable anesthesia reimbursement was calculated by multiplying the 2021 national anesthesia conversion factor by the sum of surgical base time units and anesthesia base units.[113]

The societal perspective represents the cost of lost productivity and was calculated by multiplying the nationally reported mean wages per week ($994) by the duration of disutility.[114] The duration of disutility was determined through consultation with 2 board-certified hand surgeons (S.M. and E.K.) and in accordance with their postoperative guidelines. All cost values are summarized in Table 2.

Utility estimations were collected from the literature using previously reported QALY values from Short-Form Six-Dimension

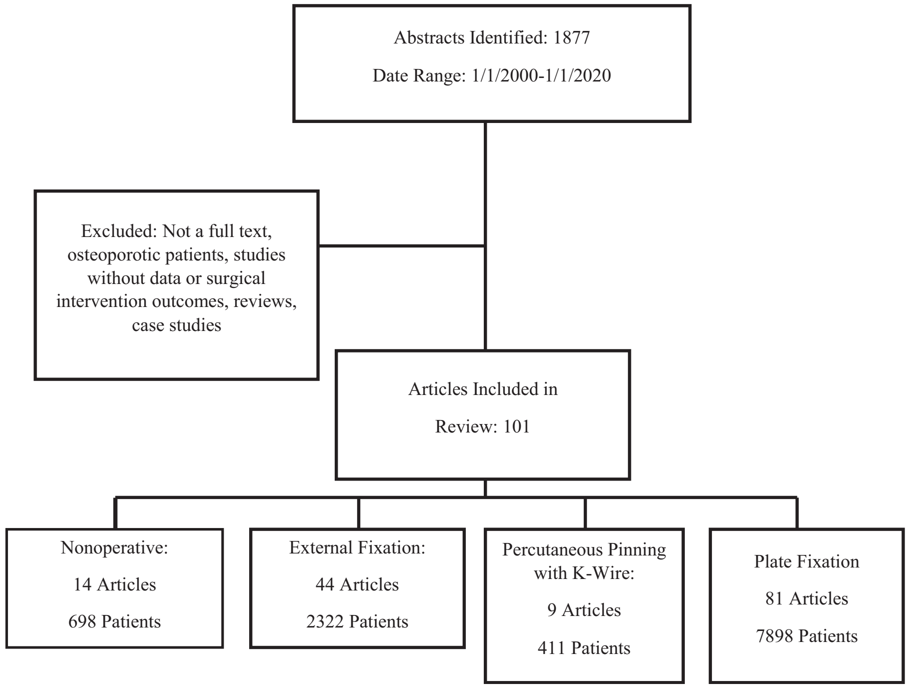

Figure 1. Flow diagram of the literature search. PubMed was queried (Appendix 2; available on the *Journal's* website at www.jhsgo.org) using general terms to capture the widest range of publications related to the complications of various management strategies for DRFs from 2000 to 2020. This search identified 1,877 abstracts. After input of exclusion criteria, 148 articles that met the criteria for the calculation of outcome probabilities remained.

Table 1
Transition-State Probabilities

Transition State	Transition-State Mean Probability		References
	Probability (%)	Range (%)	
Nonsurgical			17,19–30
Uneventful healing	74.9	26.9–96.7	
Eventful healing without further intervention	10.9	0.0–70.8	
Delayed surgical management	3.3	3.2–3.7	
Carpal tunnel syndrome	8.9	1.6–12.5	
Tendon rupture	0.3	0.3	
Trigger finger	1.0	0.0–10.0	
Percutaneous pinning			18,31–38
Uneventful healing	82.0	50.0–95.8	
Eventful healing without further intervention	9.3	0.0–44.4	
Revision surgery	4.2	2.5–10.3	
Carpal tunnel syndrome	3.9	2.5–10.0	
Tendon rupture	0.2	0.2	
Trigger finger	0.4	0.4	
Plate fixation			5,16,17–21,23–26,28,29,31,35,36,38–87
Uneventful healing	83.8	40.0–100.0	
Eventful healing without further intervention	11.9	0.0–60.0	
Revision surgery	1.8	0.0–23.6	
Carpal tunnel syndrome	3.5	0.0–14.5	
Tendon rupture	1.1	0.0–3.3	
Trigger finger	0.1	0.0–1.6	
External fixation			3,21,30,35,42,55,57,59,60,75,81–83,85–102,103,104–111
Uneventful healing	66.9	45.0–100.0	
Eventful healing without further intervention	29.7	0.0–52.7	
Revision surgery	0.9	0.0–2.9	
Carpal tunnel syndrome	3.7	0.0–5.9	
Tendon rupture	3.3	1.3–9.1	
Trigger finger	6.4	6.4	

questionnaires. Quality-adjusted life year values were assigned to each transition state in our model. Because of slight disparities in the reported literature, the QALY values for each modality were summarized and averaged. All the modalities were assigned "uneventful" healing utility: conservative (0.88), plating (0.87), wiring (0.89), and external fixation (0.87).[18,115,116] Each subsequent adverse event lowered the 1-year QALY value. Minor eventful healing was assigned a loss of 3.2%, carpal tunnel release was assigned a loss of 10%, carpal tunnel syndrome but no release was assigned a loss of 13%, and implant removal was assigned a loss of

Table 2
Health Care and Societal Costs of Initial Management

Cost Perspective	Nonsurgical	Plate Fixation	Percutaneous Pinning	External Fixation
Health care perspective				
Health care center costs ($)	108	3,654	3,653	2,651
Physician fees ($)	335	778	778	630
Anesthesia fees ($)	0	245	131	239
Total costs ($)	443	4,676	4,562	3,487
Societal perspective				
Duration of disutility (wk)	8	6	6	8
Cost of disutility per wk ($)	994	994	994	994
Total societal cost ($)	7,952	5,964	5,964	7,952
Total cost ($)	8395	10,640	10,526	11,439

7%.[117] The implant removal burden was only calculated and implemented for the plating technique because this was recognized to be an unplanned event in the treatment pathway. The QALY values for wiring and external fixation inherently include routine implant removal and, thus, were not subject to additional event labeling. Tendon rupture after DRF management that resulted in tendon reconstruction was assigned a standard value of 0.683, whereas no reconstruction was assigned 0.600.[117] Similarly, values of −0.05 and −0.1 were assigned to trigger finger release and lack of treatment, respectively. Revision surgery was deemed to be equal to QALY loss after index surgery times 1.5.[19]

Statistical analyses

All analyses were conducted from 3 perspectives of cost: societal cost, health care system cost, and total combined cost.

Rollback analysis

As a preliminary foundation for our understanding of DRF treatment, a rollback analysis was initially conducted. A rollback analysis works backward from terminal nodes toward the initial decision node, from which it determines equivalent rollback values along the way. These values are as follows:

1. At the terminal node, the rollback value is equivalent to the terminal value.
2. At the event node, the successor rollback value is multiplied by the branch probability.
3. At the decision node, the rollback value is equivalent to the highest rollback value on the immediate successor nodes.

The rollback method is quantified in terms of net monetary benefit (NMB), which is measured in dollars.

Incremental cost-effectiveness ratio (ICER)

The ICER analysis provides a ratio that portrays the resources needed to change the patient-perceived quality outcome, QALY. Because ICERs compare more than 1 test, the results provide incremental differences among modalities. In our study, we investigated the cost per QALY saved. The generic formula for cost effectiveness is as follows:

$$\frac{\text{Cost}_{\text{Treatment } A} - \text{Cost}_{\text{Treatment } B}}{\text{Effectiveness}_{\text{Treatment } A} - \text{Effectiveness}_{\text{Treatment } B}}$$

Deterministic sensitivity analysis

One-way sensitivity analyses were implemented to evaluate the changes in reference case results across varying individual parameters. The strategies were considered dominated by the reference strategy if they were both more costly and less effective. Only undominated strategies, as identified using the ICER analysis, were subjected to the sensitivity analysis. These analyses allowed us to account for the variability in outcome reporting in the DRF literature and provided us with a measure of variable impact on the ICER analysis. Incremental cost-effectiveness ratio spread, or the difference in ICER values across variable rates, is used to determine the maximal impact on the analysis. The analyses were once again subjected to willingness-to-pay (WTP) cutoff thresholds of $50,000 and $100,000.[20]

Results

Rollback analysis

The rollback analysis shown in Table 3 reports the NMB of each intervention from 3 perspectives: societal, health care system, and combined. Percutaneous pinning displayed the greatest NMB for the societal perspective, $38,047. Conservative management displayed the greatest NMB for both the health care system and combined perspectives, $42,715 and $34,738, respectively.

ICER

Table 4 shows the summary data for our ICER analysis results. We used the least-expensive strategy as our reference case for each perspective; thus, nonsurgical management was used as the reference for our health care and combined perspectives, whereas plate fixation was used for the societal perspective. A negative ICER value indicated that both the cost and effectiveness of the treatment modality were less optimal than those of the reference strategy, and, thus, the reference strategy dominated. Plate and external fixation were dominated by nonsurgical management from both the health care and combined perspectives. Percutaneous pinning resulted in a positive ICER value, which exceeded our WTP thresholds of $50,000 and $100,000 from both the health care and combined perspectives, $247,550 and $128,236, respectively. From the societal perspective, plate fixation dominated both conservative management and external fixation in terms of cost effectiveness. Percutaneous pinning showed an ICER value of $880/QALY gained and, thus, satisfied our WTP thresholds.

Table 3
NMBs of DRF Treatments

Treatment	Societal Perspective ($)	Health Care System Perspective ($)	Combined Perspective ($)
Nonsurgical	35,232	**42,715**	**34,738**
Plate fixation	37,069	38,309	32,333
Percutaneous pinning	**38,047**	39,431	33,437
External fixation	34,921	39,359	31,400

Bolded values represent greatest net monetary benefit for given modality.

Table 4
ICERs of DRF Treatments

Cost Perspective	Net Cost ($)	Difference in Cost ($)	Effectiveness (QALY)	Difference in QALY	ICER
Societal perspective					
Nonsurgical	7,977	2,001	0.8642	-	Dominated
Plate fixation	5,976	-	0.8609	−0.0199	-
Percutaneous pinning	5,993	17	0.8808	0.0166	880
External fixation	7,959	1,983	0.8576	−0.0232	Dominated
Health care perspective					
Nonsurgical	494	-	0.8642	-	-
Plate fixation	4,736	4,243	0.8609	−0.0199	Dominated
Percutaneous pinning	4,609	4,115	0.8808	0.0166	247,550
External fixation	3,521	3,027	0.8576	−0.0232	Dominated
Combined perspective					
Nonsurgical	8,472	-	0.8642	-	-
Plate fixation	10,713	2,132	0.8609	−0.0199	Dominated
Percutaneous pinning	10,604	2,242	0.8808	0.0166	128,236
External fixation	11,482	3,010	0.8576	−0.0232	Dominated

Deterministic sensitivity analysis

Because percutaneous pinning was the only surgical outcome not dominated by conservative management from the health care perspective, 1-way sensitivity analysis was conducted using all variables of percutaneous pinning and nonsurgical management. The rates of uneventful healing after percutaneous pinning had the largest ICER spread among any variables (704,924), although only at successful rates of 92.5% and higher did we see percutaneous pinning cross the WTP threshold of $100,000. If the success rates of uneventful healing after conservative treatment dropped below 57.6%, we would similarly see percutaneous pinning become more cost effective. Lastly, if conservative rates of delayed surgical management or trigger finger release increased above 2.8% and 8.1%, respectively, percutaneous pinning would be more cost effective at the WTP threshold of $100,000. No other outcomes significantly impacted our model. All sensitivity results are presented as a tornado diagram in Figure 2.

Discussion

When both surgical and nonsurgical interventions for the treatment of DRFs were investigated, on average, nonsurgical management was found to be the most cost-effective measure. This finding is the result of significantly decreased health care costs while retaining similar effectiveness compared with those of the other modalities. However, nonsurgical treatment did report the highest societal cost because of days of lost productivity, which may have been an important qualifier while discussing treatments with patients; however, these values may vary with fracture healing times and individual provider postoperative guidelines.

In terms of total costs, external fixation was the costliest methodology, mediated by its heightened postoperative disutility period and associated complications. Nonsurgical management similarly displayed heightened weeks of disutility but eliminated the surgical costs associated with external fixation. The increased cost of external fixation did not present with a sizable cost benefit either; in fact, external fixation demonstrated the least cumulative effectiveness out of all the intervention strategies (QALY, 0.8576).

Interestingly, plate fixation was dominated by the other treatment modalities from both the health care and combined perspectives. Like external fixation, this was largely due to increased cost and decreased effectiveness. Decreased effectiveness likely stems from additive procedural costs and disutility because of implant removal and revision surgery. In fact, plate fixation displayed the greatest rate of warranted revision surgery (4.9%). With recent reports (2020) suggesting that greater than 80% of surgical interventions for DRFs use open reduction internal fixation,[21] these findings may question DRF treatment trends in orthopedics. Nevertheless, these tendencies in orthopedic management may have already seen shifting tides. The Distal Radius Acute Fracture Fixation Trial, based in the United Kingdom, conducted an "in-house" cost-evaluation trial of 461 patients assigned to undergo either percutaneous pinning with K-wire or volar plate fixation and similarly concluded percutaneous pinning to usurp plate fixation from a cost-effectiveness standpoint.[22] Costa et al[23] sought to evaluate the clinical impacts related to the Distal Radius Acute Fracture Fixation Trial's discoveries and revealed a significant increase in percutaneous pinning with K-wire relative to plate fixation, thus warranting a re-evaluation of the current clinician standpoint on optimal treatment strategies.

Compared with the present study, the Distal Radius Acute Fracture Fixation Trial possessed many important advantages with their "in-house" evaluation, as opposed to a systematic review approach. They were able to standardize the cost, effectiveness, patient demographics, and surgical approach to provide the most empirical cost-effectiveness data in the literature to date, and they should be commended for potentially restructuring the surgical algorithm in the United Kingdom. However, by design, these findings are also self-limiting. The present study sourced data from over 100 articles, which encapsulated over 10,000 patient outcomes, which may yield greater generalizability for surgeons around the world. Although Rajan et al[117] similarly used a systematic review for the determination of the cost effectiveness of treatment modalities for DRFs, this study is unique in our approach of

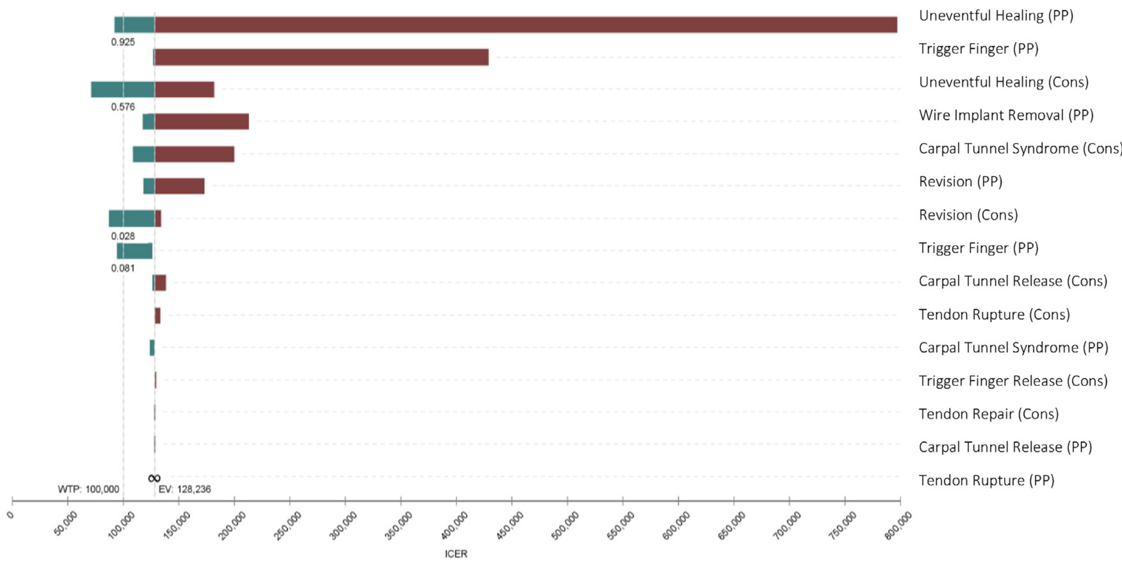

Figure 2. Tornado diagram of nonsurgical management versus that of percutaneous pinning after DRF. The expected value of percutaneous pinning, relative to that of conservative treatment, resulted in $128,236 incremental dollars per QALY. Bars extending toward the right of the expected value line indicate lesser cost effectiveness of percutaneous pinning relative to alterations in probability reporting of the variables on the y axis. Bars extending toward the left of the expected value line indicate greater cost effectiveness. The willingness to pay was set at a threshold of $100,000. Bars extending through the willingness-to-pay line indicate that percutaneous pinning is more cost effective at the variable probability thresholds listed. Cons, conservative; EV, expected value; PP, percutaneous pinning; WTP, willingness-to-pay.

investigating 4 different treatment modalities in conjunction with specific transition states of adverse events to identify the optimal intervention.

Other studies have reached varying conclusions on the relative cost effectiveness of treatment options for DRFs. In a randomized study of patients aged 65 years and older with displaced DRFs, Hassellund et al[24] found that volar plating was not cost effective compared with nonsurgical treatment from the health care perspective despite significantly higher health-related quality of life associated with surgical treatment. In a randomized study of patients aged 50–74 years with unstable dorsally displaced fractures, Saving et al[25] found that volar plating resulted in higher costs and a smaller quality of life benefit compared with external fixation. Yoon et al[26] concluded that casting and percutaneous pinning were the most cost-effective treatment strategies for closed extra-articular fractures and closed unstable fractures, respectively, in patients aged 60 years and older. Karantana et al[115] found that volar locking plate fixation was not more cost effective than percutaneous fixation for dorsally displaced DRFs. These studies, in combination with our findings, suggest that despite the popularity of volar locking plate fixation, this technique is less cost effective than other treatment options.

Despite comprehensive inclusion of the DRF treatment elements, our study presents with notable limitations. First, utility estimation in orthopedics is a difficult and subjective measure that can be a source of disagreement among similar studies. We attempted to source and average as many congruent QALY values as possible from the literature to combat the heterogeneity of reporting data. However, QALY data in the DRF literature remain limited at this time. Second, our study did not consider fracture classifications, such as those by the Orthopaedic Trauma Association, or patient age, which may have reasonably altered the significance of our findings. A recent Swedish nationwide study of 22,962 patients with DRF noted significant discordance in the treatment approach and Orthopaedic Trauma Association fracture classification.[21] Unfortunately, the lack of literature stratifying outcomes based on Orthopaedic Trauma Association fracture types and age while maintaining detailed outcome reporting made this sort of delineation impossible at this time. One cost-effectiveness study did attempt to isolate fracture type by only evaluating intra-articular fractures among volar plate and nonsurgical measures. They concluded that plate fixation was actually more cost effective than nonsurgical management. Although dissimilar in modality inclusion, the findings further illustrate the need for better fracture and age reporting for outcome-based studies going forward.[118] Our study did not employ Monte Carlo simulation to predict the probability of different outcomes. This is a potential avenue for future research. Finally, although we reported the advantages of the cost-effectiveness analyses, performed using a systematic review process, this methodology caused us to include varying levels of evidence in our assessment, which may have limited the utility of our findings, which includes professional estimation of postoperative time course that may conflict with different fracture types.

Given these limitations, we offer physicians the following recommendations to interpret and adapt our conclusions into their practice: when accounting for various outcomes and adverse events, nonsurgical management presents as the most cost-effective treatment option for the sum total of all DRFs, irrespective of age and fracture type. On the other hand, in populations in which the success rates of nonsurgical management are lower or the rates of adverse events are higher, percutaneous pinning has been shown to be a dominant strategy. Thus, surgeons should internally audit their patient population and health care system in order to adopt our aggregated results into their practice.

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