

Markov Models for Cost-Effectiveness Analysis of Knee Arthroscopy: A Systematic Review

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Objectives: To review the existing literature on the cost-effectiveness of knee arthroscopy procedures.

Design: A systematic review of study designs involving a Markov model or probabilistic cost-effectiveness analysis specific to knee arthroscopy

Main Outcome Measurements: estimates of cost-effectiveness, including incremental cost-effectiveness ratio (ICER) comparisons and cost per quality-adjusted life year (QALY) ratios.

Results: The initial search identified 474 studies, with 7 articles meeting the inclusion criteria after screening and review. The included studies exhibited heterogeneity in participant demographic, design, interventions, and outcomes. Most studies reported superior cost-effectiveness in favor of meniscus repair and against meniscectomy. Additional analyses included evidence favoring diagnostic needle arthroscopy to MRI; early drilling of osteochondral defects to nonoperative management; and early intervention to delayed treatment.

Conclusions: This review demonstrated substantial variability in estimates of cost-effectiveness, methodologies, and outcomes within the literature on knee arthroscopy procedures. Despite the heterogeneity, several trends emerged indicating favorable cost-effectiveness for several arthroscopic procedures for knee pathology. However, disparities in methodology and the lack of standardized reporting guidelines pose limitations to the generalization of these interpretations. Future research should focus on standardized methodologies and reporting, as well as long-term clinical and economic studies. This review underscores the need for larger data sets for assumptions made in Markov models used in assessing the cost-effectiveness of knee arthroscopy procedures.

Level of Evidence: Level IV; systematic review of level IV evidence or higher

Key Words: Markov model, knee arthroscopy, cost-effectiveness, QALY

INTRODUCTION

Research has shown the importance of the financial implications of healthcare decisions.^{1,2} Reimbursement³⁻⁶, economic incentives⁷, and the

value of more efficient pathways have been highlighted in recent research.⁸⁻¹⁰ In addition, the discrepancies in cost, charges¹¹, and collections¹² often obscure accurate data. As a result, many findings related to business aspects of orthopaedic surgery are unable to be generalized.¹³ To facilitate improvements in the scholarship regarding cost-effectiveness, it is important for orthopaedic surgeons to better communicate regarding these topics and establish consensus by reviewing existing literature.^{14,15}

The economic implications of frequently performed procedures such as knee arthroscopy have become a key area of focus. However, assumptions, methodology, and cost estimates vary widely within the current literature. Many studies on the economic implications of procedures use data solely from their own institutions.¹⁶ However, a systematic review containing the largest number of varying results, even if they are disparate, may provide more accurate conclusions.¹⁷ In fact, composite measures from dissimilar cost estimates have been shown to

converge in studies with the best methodology.¹⁸ Therefore, a large review of studies is essential to arrive at a reliable estimate of costs for frequently performed procedures like knee arthroscopy.

In 1906, Andrey Markov first defined the Markov model as a probabilistic framework used to analyze the transition of individuals or systems between a set of states over time.¹⁹ In the medical setting, a Markov model can simulate the progression of patients through different health states over time, allowing us to estimate the cumulative quality-adjusted life years (QALYs) gained and associated costs for various medical interventions or treatment strategies.²⁰ Through computer-based simulations, Markov models offer insights into the potential long-term impact of interventions on both health outcomes and economic considerations. The purpose of this study is to review the existing literature on the cost-effectiveness of knee arthroscopy procedures to assess the variability in methodologies and results across different analyses utilizing the Markov model.

METHODS

This systematic review was performed following PRISMA guidelines for methodology and reporting. Eligibility criteria were determined by

study design, intervention, and outcome measures. We included studies utilizing a Markov model or probabilistic analysis of the cost-effectiveness of any knee arthroscopy procedure. Interventions included meniscus repair, meniscectomy, autologous chondrocyte implantation, mosaicplasty, ACL reconstruction, osteochondral defect drilling, debridement, diagnostic arthroscopy, and needle arthroscopy. Outcome measures included incremental cost-effectiveness ratio (ICER), which compares two or more interventions; we also included studies that reported cost per QALY and cost savings, which describe the value of a single procedure. Studies were excluded if the study differed in overall design, the intervention did not involve knee arthroscopy, or if the full English text was unavailable.

A search was performed in Google Scholar via Harzing PoP software version 8.19²¹ for the following keywords: “Markov” AND “knee arthroscopy”. Results from all years were obtained. All results were cataloged and independently reviewed by two authors. In the first phase, study titles were screened for eligibility. The remaining abstracts were screened and for those that met the inclusion criteria, full articles were reviewed.

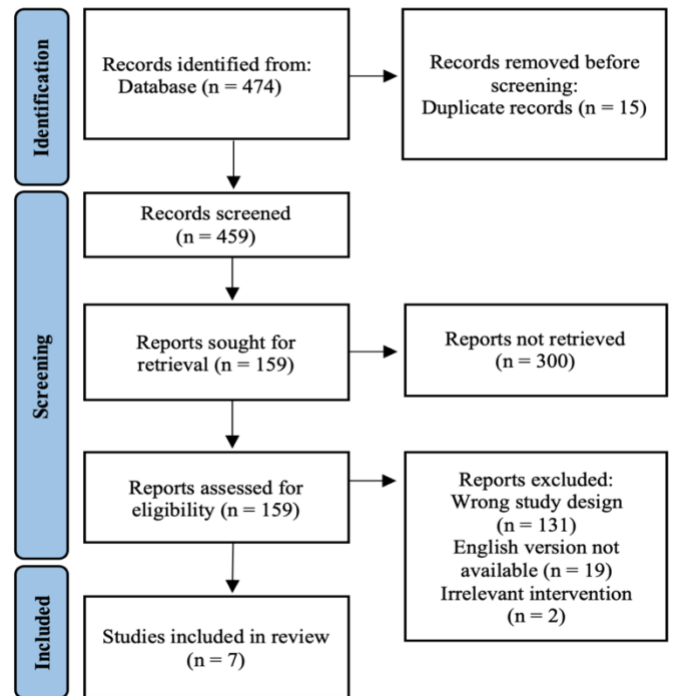
Data collected from articles included study aim, study type, methodology, duration, population, intervention, and outcome measures; we also compiled data specific to the computer-based simulations including the cycle length, horizon, and total number of simulations. Where available, the ICER was the primary outcome extracted or calculated to compare the differing costs of the compared interventions. We extracted the fiscal year for the cost estimate when available and used the publication year when it was not. All figures were adjusted for inflation to 2023 dollars.

RESULTS

The search yielded 474 studies. 15 were eliminated due to duplication of search results. 300 additional studies were excluded after abstracts were screened for the involvement of knee arthroscopy. Of the remaining 159 full-text articles reviewed, 131 differed in overall design, 19 did not have an English text available, and 2 studies reported irrelevant interventions. Ultimately, 7 articles were included after screening and review²²⁻²⁸ (Figure 1).

The ages of participants varied, with most studies reporting on middle-aged and elderly adults

Figure 1: PRISMA flow diagram of studies from search through screening to inclusion and exclusion



and one study focusing on skeletally immature patients (Table 1).

The included analyses also exhibited heterogeneity in methodology, interventions, and measured outcomes. Specifications for the Markov simulations varied greatly with cycles ranging from 1 month to 2 years, horizons ranging from 2 to 40 years, and simulations ranging from 10,000 to 100,000. The majority of studies reported superior cost-effectiveness in favor of meniscus repair and against meniscectomy.^{23,25,27,28} If a partial meniscectomy was done in the case of symptomatic osteoarthritis, early intervention tended to be more cost-effective when compared to delayed treatment.²⁶ In a study evaluating the treatment of

Table 1: Includes 7 Markov model cost-effectiveness analyses of procedures involving knee arthroscopy.

Author (year)	Method Cycle Horizon Simulations	Population	Treatments	Measure	Value	Result
Amin et al (2019) ²²	Markov 1 year 2 years 10,000	Symptoms of meniscal lesion in middle-aged patients	Needle arthroscopy vs. MRI	Cost savings per diagnosis	\$392– \$2281 saved	Favors needle arthroscopy
Faucett et al (2019) ²³	Markov 1 month 5/10/20/30/ Life 10,000	Meniscus root tears without osteoarthritis in patients aged 51– 58	Meniscectomy vs. meniscus repair vs. nonoperative management	ICER	\$31,880 per QALY (10 years) \$15,546 per QALY (10 years)	Favors meniscus repair over meniscectomy Favors meniscus repair over nonoperative management
LeBrun et al (2021) ²⁴	Markov 1 week 3 years	Stable OCD of the knee in skeletally immature patients	Early drilling vs. nonoperative management	ICER	\$7,037 per QALY	Favors early drilling
Lester et al (2018) ²⁵	Markov 1 year 40 years 10,000	ACL tears with a peripheral longitudinal meniscal tear at either the red– white or red–red zone	ACL + meniscus repair vs. ACL + partial meniscectomy	ICER	\$10,217 per QALY	Favors meniscus repair
Losina et al (2015) ²⁶	Markov 3 months 10 years 10,000	Symptomatic meniscal tear with knee osteoarthritis in patients aged over 45	Immediate arthroscopic partial meniscectomy vs. delayed arthroscopic partial meniscectomy vs. physical therapy	ICER	\$16,994 per QALY \$135,952 per QALY	Favors delayed arthroscopic partial meniscectomy over physical therapy Favors immediate arthroscopic partial meniscectomy over delayed arthroscopic
Rogers et al (2019) ²⁷	Markov 1 year 40 years	Isolated red-red zone, vertical meniscal tears in patients aged under 40	Isolated meniscus repair vs. partial meniscectomy	ICER	\$5,039 per QALY	Favors isolated meniscus repair
Rongen et al (2018) ²⁸	Markov 1 year 9 years 100,000	Degenerative meniscal tears in patients aged over 50	Arthroscopic meniscectomy vs. nonoperative management	ICER	\$237,593 per QALY	Against meniscectomy

osteochondral defects in skeletally immature patients, early drilling was found to be more cost-effective than nonoperative management.²⁴ Another study provided evidence in favor of diagnostic needle arthroscopy compared to MRI in patients with symptomatic meniscal lesions.²² In this particular case, authors reported outcomes as cost savings per diagnosis made via needle arthroscopy when compared to MRI.²² In every other study, the measured outcome was reported as ICER, or the

authors provided enough information for the ICER to be calculated.²³⁻²⁸

DISCUSSION

This study aimed to systematically review the existing literature on the cost-effectiveness of knee arthroscopy procedures. The findings of this review demonstrated significant variability in the estimates of cost-effectiveness, as well as methodology and results across the included studies.

The variability observed in the estimates of cost-effectiveness among the reviewed studies is a

noteworthy outcome. The diverse range of cost estimates highlights the complexity and challenges associated with accurately determining the economic implications of knee arthroscopy procedures. Factors such as variations in study populations, selection criteria, interventions, outcomes, and cost calculation methodologies contribute to the heterogeneity of results. Additionally, the lack of standardized reporting guidelines for cost-effectiveness studies in orthopedic surgery further compounds the issue. These findings underscore the need for more consistent and rigorous methodologies in future studies to enable meaningful comparisons and improve the generalizability of the results.

Despite the wide range of cost estimates and interventions assessed, it is worth noting that most of the reviewed studies indicated favorable cost-effectiveness for meniscus repair and against meniscectomy. This suggests that knee arthroscopy procedures may offer economic value in certain clinical scenarios; however, further research is needed to substantiate this finding.

The timing of meniscectomy following symptom onset emerged as another important consideration in the cost-effectiveness of knee arthroscopy. Early intervention was generally

associated with better cost-effectiveness outcomes compared to delayed treatment. This finding suggests that prompt surgical management may result in better clinical and economic outcomes, highlighting the potential benefits of timely interventions in knee arthroscopy procedures. Further research is needed to determine the optimal timing for surgical intervention and to better evaluate the long-term economic implications of different treatment strategies.

Several limitations need to be acknowledged when interpreting the results of this systematic review. First, as stated previously, the included studies exhibited considerable inconsistencies in terms of study design, interventions, and outcomes, which limits the ability to draw definitive conclusions. The variability in cost estimation methodologies and the lack of standardized reporting guidelines for cost-effectiveness studies pose challenges in synthesizing the findings. Additionally, the reliance on published literature introduces the possibility of publication bias and limits the generalizability of the results to other settings or populations.

Table 2: 6 non-Markov model cost-effectiveness analyses of procedures involving knee arthroscopy.

Author (year)	Method Duration	N	Population	Treatments	Measure	Value	Result
Blatnik et al (2017) ²⁹	Cost utility analysis 1 year	43	Knee arthroscopy in any patient	Inpatient vs. outpatient knee arthroscopy	ICER	Dominant	Favors outpatient knee arthroscopy
Derrett et al (2005) ³⁰	Cross-sectional retrospective cohort study 2 years	95	First ACI or mosaicplasty for chondral or osteochondral lesions of 1 cm diameter or more in patients aged 16–49	Autologous chondrocyte implantation vs. mosaicplasty	ICER	\$47,815 per QALY	Favors autologous chondrocyte implantation
Hutt et al (2015) ³¹	Prospective study 1.5 years	211	Radiological OA on plain radiographs and mechanical symptoms in patients aged 35–82	Arthroscopic debridement	Cost per QALY	\$3,733 per QALY	Arthroscopic debridement is cost-effective
Lubowitz et al (2011) ³²	Retrospective analysis 2 years	93	Any knee arthroscopy procedure in patients aged 11–79	Knee arthroscopy	Cost per QALY	\$8,309 per QALY	Knee arthroscopy is cost-effective
Marsh et al (2015) ³³	Randomized control trial 2 years	168	Symptomatic, radiographic knee OA in patients on disability or aged over 65	Arthroscopic debridement and partial meniscectomy + nonoperative therapy vs. nonoperative management	ICER	\$143,396 per QALY	Against arthroscopic debridement and partial meniscectomy
van de Graaf et al (2020) ³⁴	Randomized control trial 2 years	321	MRI-confirmed non-obstructive meniscal tears in patients aged 45–70	Arthroscopic partial meniscectomy vs. physical therapy	ICER	\$86,001 per QALY	Against partial meniscectomy

Future research evaluating the cost-effectiveness of knee arthroscopy should aim to address these limitations and provide more robust evidence. We identified several cost-effectiveness analyses that reported the same outcome measures but were ultimately excluded due to their use of less impactful methodologies (Table 2).²⁹⁻³⁴ Standardized methodologies for cost estimation, such as the use of consistent analytic tools, outcome measures, and reporting guidelines, would enhance the comparability and reliability of these studies. Additionally, long-term follow-up studies that capture both clinical and economic outcomes are necessary to evaluate the cost-effectiveness of knee arthroscopy procedures comprehensively. An increased number of studies examining the cost-effectiveness of less common techniques or

technologies, such as autologous chondrocyte implantation and mosaicplasty, would further expand our understanding of the economic implications of knee arthroscopy.

This systematic review highlights the wide variability in cost-effectiveness estimates, methodologies, and interventions in the literature on knee arthroscopy procedures. The most prevalent finding suggests that knee arthroscopy, specifically meniscus repair, may offer favorable cost-effectiveness compared to meniscectomy or nonoperative management. However, caution is warranted due to the limitations and heterogeneity of the included studies. Standardization of methodologies and reporting guidelines, along with long-term follow-up studies, are crucial to enhance

the reliability and applicability of future research in this field.

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