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REVIEW

COST-EFFECTIVE OUTPATIENT ARTHROPLASTY WORLDWIDE IN 2025

Enabling technologies in outpatient total joint arthroplasty: an international review with application to Italian Healthcare Policy

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ABSTRACT

BACKGROUND: The growing prevalence of outpatient total joint arthroplasty (TJA), driven by rising costs and declining reimbursement, has accelerated the adoption of technology-assisted solutions to enhance safety, efficiency, and cost-effectiveness. Enhanced Recovery After Surgery (ERAS) protocols have provided a strong clinical foundation, emphasizing patient education, multimodal analgesia, and early mobilization. Building upon these principles, enabling technologies – such as robotics, artificial intelligence, telemedicine, and digital engagement platforms – are being increasingly integrated across all perioperative phases to optimize outpatient arthroplasty outcomes. To date, limited evidence has addressed the integration of clinical, ERAS-supported perioperative practices with emerging enabling technologies in arthroplasty; the present study aims to fill this gap in knowledge by examining how these innovations can improve outcomes and cost-efficiency in outpatient joint replacement.

METHODS: This study examined the available literature on enabling technologies applied to the preoperative, intraoperative, and postoperative phases of outpatient TJA. Evidence was gathered from published studies, consensus statements, and clinical registry data, including a registry from the authors' country. Preoperatively, telemedicine and Artificial Intelligence-driven risk stratification improve patient selection and optimization, while digital nutrition and education platforms enhance readiness and compliance.

RESULTS: Intraoperatively, enabling technologies increase accuracy and reproducibility without compromising surgical time once the learning curve is achieved, while simultaneously reducing length of stay, rates of complications, and rates of readmission. Postoperatively, remote monitoring, telemedicine, and telerehabilitation have proven cost-effective, ensuring patients' comfort, functional outcomes, and safe recovery. Registry data from the Autonomous Province of Bolzano showed that up to 25% of patients with low anesthetic risk and adequate home support could safely undergo outpatient arthroplasty, with potential annual national cost savings exceeding €3 million.

CONCLUSIONS: Technology-enabled, ERAS-integrated outpatient arthroplasty pathways can reduce morbidity, readmissions, and healthcare costs while improving patient satisfaction and sustainability. Wider implementation requires supportive reimbursement models and further multicentric validation, particularly in healthcare systems outside the USA.

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KEY WORDS: Arthroplasty; Enhanced Recovery After Surgery; Program evaluation.

Introduction

In the USA, physician reimbursement for orthopedic total joint arthroplasty (TJA) procedures has shown a concerning and significant decline. Additionally, outpatient arthroplasty, especially for hip and knee replacements, is becoming more common and is covered by Medicare.[1] Medicare is a federal health insurance program in the USA for individuals aged 65 and older and those with disabilities or certain chronic medical conditions. This system is not entirely free because a flat fee is charged to cover specific healthcare services or medication costs.[1] However, Medicare's reimbursement rates for these procedures have been declining, impacting both patients and providers and prompting surgeons to seek alternative and "cost-effective" options. North American adult reconstruction surgeons, working within public and private healthcare systems globally, are currently developing "cost-effective" models to establish privately-owned Ambulatory Surgery Centers (ASCs) and outpatient arthroplasty programs in major hospitals.[2] Following this trend, outpatient arthroplasty is gaining popularity in a few countries outside the USA, such as Denmark and the Netherlands. Interestingly, in 2001, a group dedicated to Enhanced Recovery After Surgery (ERAS)® was formed in Europe to advance perioperative care and enhance post-surgical recovery. This project focuses on the development of a perioperative protocol, which encompasses proper patient selection and close collaboration among three "teams": medical, anesthesia, and surgical. In 2020, a multidisciplinary consensus was reached after reviewing the literature and proposing recommendations for the perioperative care of patients undergoing TJA with an ERAS program:[3] 17 components were selected, including optimizing preoperative patient education, anesthetic techniques, transfusion strategies, opioid-sparing multimodal analgesic approaches, and early mobilization protocols.

A recent systematic review[4] assessed the use of multiple ERAS components in TJA to determine the most effective ones; preoperative patient education (79.2%), local infiltration analgesia (LIA) or nerve blocks (79.2%), perioperative oral analgesia (66.7%), reduced use of tourniquets and drains (41.7%), use of tranexamic acid (41.7%), and early mobilization (100%) were identified as the top components of an enhanced recovery protocol. These and other ERAS clinical protocols provide a potential foundation for creating technology-driven platforms that support patients undergoing TJA. To date, few studies have examined how clinical, ERAS-supported practices for TJA are integrated with intraoperative technology platforms such as computer navigation, robotics, augmented reality, and digital systems for remote patient monitoring.

This study aims to demonstrate how various enabling technologies can enhance outcomes and reduce costs in outpatient arthroplasty. A narrative review was conducted to identify gaps in the literature supporting the implementation of outpatient TJA programs during a time when enabling technologies are transforming the overall approach to healthcare. Data from the authors' regional joint replacement registry was analyzed and reported to estimate the potential impact of implementing an outpatient arthroplasty program in the authors' area.

Methods

Outpatient TJA represents a new reality worldwide.[5] Even in high-volume USA academic centers, outpatient total knee arthroplasties (TKA) have surpassed inpatient procedures[5, 6] without affecting outcomes. In the USA, economic issues and rule changes have led to a sharp rise in the use of ASCs, with use increasing by 84% in 2022 alone.[5, 6] This increasing trend could grow exponentially as technology-enabled programs are incorporated into the preoperative, intraoperative, and postoperative stages of TJA.

A narrative review of the literature was conducted to emphasize the key components of a successful outpatient TJA program that utilized enabling technologies. The authors used their institutional databases: Scopus by Elsevier, Amsterdam, The Netherlands. The search was conducted on September 1st, 2025, and all published articles, including original articles, case series, and reviews, were included. The original search terms included "outpatient arthroplasty" and "enabling technologies" to align with the

main objective of the current study. Interestingly, only one article was found.[7] However, when the search terms included "ambulatory surgery center," "robotics," and "navigation," 44 articles were identified. From these search results, only two registries reporting the outpatient arthroplasty rate were identified and ultimately included in the current review.[8, 9] A retrospective analysis of outpatient arthroplasty from the English National Health Service was included as well.[10] Recommended interventions were documented throughout the preoperative, intraoperative, and postoperative stages.

Finally, 10 years of data from 2010 to 2020 from the Autonomous Province of Bolzano (Italy) Joint Replacement Registry were analyzed and reported to inform an assessment of the current policy on outpatient arthroplasty in Italy. As a narrative review utilizing data from a public registry, this study did not require Internal Review Board (IRB) approval.

Results

Recommended interventions

Total joint arthroplasty preoperative phase

Accurate patient selection and preoperative optimization are essential for safety and efficiency as outpatient arthroplasty expands to ACSs, and enabling technologies can significantly support this process.[11] Telemedicine pre-anesthesia evaluations have been shown to provide safe patient care while reducing patient inconvenience and cost compared to in-person assessments.[12] Indeed, a 2023 scoping review examined alternatives to traditional anesthetist-led preoperative assessments, such as telephone, telemedicine, and questionnaire-based evaluations, and found lower surgery cancellation rates, comparable 30-day mortality, high patient satisfaction, and an average cost savings of about USD 20 per visit (IQR 15-28).[13]

Furthermore, artificial intelligence (AI)-based algorithms and machine-learning applications have already shown their ability to support more streamlined and efficient preoperative risk stratification, potentially reducing the workload on assessment teams and improving resource allocation.[14]

Interestingly, a machine learning study by Gabriel *et al.*[15] at an ambulatory surgery center found that ensemble-based predictive models could accurately determine whether an additional case would be completed and discharged within the scheduled block time, outperforming traditional regression techniques. Such tools can assist with preoperative scheduling and case selection, reducing workflow bottlenecks and enabling efficient same-day discharge in outpatient arthroplasty programs. Furthermore, although most evidence on digital nutrition platforms comes from the general population,[16] their use in arthroplasty patients could significantly improve preoperative preparation. Integrating AI-driven precision-nutrition tools into ERAS pathways could enable real-time dietary monitoring, early detection of malnutrition, and personalized nutritional guidance, ultimately enhancing metabolic readiness and recovery in outpatient arthroplasty care. Surgeons involved in the 2018 International Consensus Meeting (ICM) on PJI have already recommended the use of periprosthetic joint infection (PJI) risk calculators[17] to reduce the risk of PJI in patients undergoing primary or revision TJA.

Turcotte *et al.*[18] have recommended a predictive model for same-day discharge (SDD) after total knee arthroplasty: for patients undergoing primary total knee arthroplasty, factors such as increased age, a Body Mass Index of 35, female gender, nonwhite race, primary hypertension, three comorbidities, and an American Society of Anesthesiologists (ASA) score of 3 decrease the likelihood of SDD. Once the patient has been scheduled for surgery, preoperative education can deliver essential information about perioperative exercise, rehabilitation, and expectations regarding the length of stay (LOS). The use of enabling technologies and digital patient engagement platforms – combining portals, mobile apps with preoperative education mobile applications and chatbots – has been linked to improved compliance, shorter LOS in patients undergoing TJA,[19] enabling patients to take part in their healthcare journey while easing the workload on clinic staff.[20]

Total joint arthroplasty intraoperative phase

The surgical intervention must be performed promptly, consistently, reproducibly, and reli-

ably. The use of enabling technologies offers the theoretical benefit of supporting these objectives. Intraoperative enabling technologies include robotics, computer navigation, patient-specific instrumentation, and augmented reality. There is significant debate about the cost and intraoperative value of these technologies in an ASC. Unlike many large hospital systems, especially academic ones, independent ASCs often struggle with slow, bureaucratic procedures when implementing new intraoperative technologies.

There is a misconception that using robotics and computer navigation extends surgical times. In reality, once the natural learning curve is complete (about 40 cases),[21] robotic-assisted primary TKA decreases the surgical time, inpatient length of stay, and 90-day complication and readmission rates of complex TKA to the levels seen in non-complex TKA.[22] Furthermore, robotic-assisted surgery seems to lower complications, especially in outpatient settings, and could improve outpatient care pathways.[23] In another comparative analysis, robotic-assisted surgery has been shown to significantly reduce postoperative events at 90 days compared to traditional surgery.[24] Strategies such as applying lean principles have recently been adopted to lower the carbon footprint, costs, and logistical burden of robotic-assisted TKA, making these technologies more compatible with outpatient arthroplasty models.[25] On the other hand, computer navigation, which was implemented in TKA over 25 years ago to enhance accuracy and precision in component placement, is now declining in popularity in both traditional and outpatient surgical settings due to longer intraoperative times compared to robotic-assisted surgery.[26]

Total joint arthroplasty postoperative phase

Enabling technologies are significantly influencing the postoperative period after outpatient arthroplasty. In fact, the growing trend toward outpatient procedures further increases the need for remote monitoring solutions. As a result, remote recovery monitoring technologies have rapidly expanded over the past decade. These innovations allow for objective tracking of mobility and function, gait analysis, prediction of complications (*e.g.*, infection, instability, stiffness), monitoring rehabilitation adherence, and assessing patient-reported symptoms and outcomes.[27]

Early mobilization plays a key role in early discharge after TJA.[2] DeRogatis *et al.*[28] compared two groups of patients, with and without remote home monitoring, and found lower readmission rates in the remote monitoring group, along with significantly fewer ED visits: the control group had notably higher 30-day readmission rates due to syncope, postoperative pain, cellulitis, hip dislocation, and postoperative fever caused by atelectasis. A study by Van Overshelde *et al.*,[29] during the COVID-19 pandemic, showed that shortening the length of stay from three to one night after total knee or hip arthroplasty, aided by a digital follow-up tool, maintained stable rates of complications, readmissions, and similar clinical outcomes, while reducing the socio-economic burden on the healthcare system. Similarly, data from New York City during the early months of the COVID-19 pandemic showed that telemedicine can effectively replace traditional in-person postoperative visits in outpatient arthroplasty: virtual consultations lowered healthcare costs for more than half of the patients, reduced anxiety and travel-related stress, enhanced comfort through at-home evaluations, and even enabled direct assessment of the postoperative living environment.[30] Additionally, a randomized controlled trial published in 2021 confirmed that a virtual physical therapy program with remote clinician oversight after TKA significantly reduced 3-month healthcare costs and readmissions (median $ 1050 *vs.* 2805), while maintaining comparable functional outcomes and safety compared to standard in-person rehabilitation.[31]

Collectively, these and other studies[32, 33] have strengthened the value of telemedicine and telerehabilitation, encouraging the use of mobile apps as an effective tool to boost outpatient arthroplasty procedures.[34]

Regional joint replacement registry

The authors analyzed data from their regional Joint Replacement Registry, established in 2010, through 2020 (Autonomous Province of Bolzano, Italy).

From 2010 to 2020, a total of 19,367 procedures (Figure 1) were included in the regional

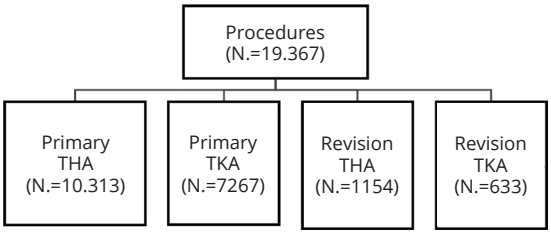

Figure 1.—Autonomous Province of Bolzano Joint Replacement Registry. Number of arthroplasty procedures performed between 2010 and 2020.
THA: total hip arthroplasty; TKA: total knee arthroplasty.

registry: 10,313 were primary THA, 7267 were primary TKA, 1154 were revision THA (rTHA), and 633 were revision TKA (rTKA). The average age at the time of the procedure was 69±9 years. No significant difference in the female-to-male ratio (1.0±0.1) was observed during the study period. The ASA scores were 1 in 22%, 2 in 65.5%, and 3 in 12.5%. THA revision rates were 1.4% (95% CI 1.1-1.7) after 1 year and 3.0% (95% CI 2.6-3.4) at the 5-year follow-up; TKA revision rates were 1.1% after 1 year (95% CI 0.8-1.4) and 3.7% after 5 years (95% CI 3.1-4.4) (Table I). The rate of missing procedures was 3% for primary procedures and 14% for revision procedures. Interestingly, among patients with a low ASA classification (<III) undergoing primary arthroplasty, aged under 75, and supported at home during the initial postoperative days, our analysis found that a quarter of all patients (25%) might have qualified for outpatient joint arthroplasty. Considering that the daily cost of hospitalization in Italy is approximately € 674,[35] our study estimated that switching from inpatient to outpatient arthroplasty could result in a total savings of € 3.25 million.

Discussion

Our review of the international literature on the use of enabling technologies for outpatient arthroplasty in ambulatory surgery center settings shows that there are still not enough studies evaluating the support provided by enabling technology-based interfaces to clinical ERAS practices for total joint arthroplasty in general and outpatient arthroplasty, in particular.

A 2025 review involving nearly 294,000 patients across different studies showed that ERAS pathways reduce hospital stays by one to three days without increasing readmission rates or complications,[36] speeding up functional recovery, and providing significant cost savings across the system. The growing use of ERAS principles has, in turn, enabled safe same-day discharges and expanded outpatient arthroplasty programs for carefully selected patients.

Jayakumar *et al.*[37] described a patient-centered, technology-enabled program for primary total hip (THA) and knee arthroplasty: the authors utilized an industry-supported software platform that integrates health services and multimedia components with existing ERAS protocols. The health service features included modified joint schools, accelerated physical therapy, and outreach services; the multimedia elements included patient-specific websites, healthcare provider websites, patient education materials, and DVDs.[37] The implementation of this program led to a 42% decrease in length of stay and a significant increase in patient satisfaction. These authors[37] also measured and reported cost savings for the public healthcare system in which the program was used; notably, the program was

TABLE I.—*Details of arthroplasty procedures performed between 2010 and 2020 (N.=19,367).*

Demographics	Value
Mean age (years)	69±9
Female-to-male ratio	1.0±0.1
ASA score	
ASA 1	22%
ASA 2	65.5%
ASA 3	12.5%
THA revisions at 1-year follow-up	1.4% (95% CI: 1.1-1.7)
THA revisions at 5-year follow-up	3.0% (95% CI: 2.6-3.4)
TKA revisions at 1-year follow-up	1.1% (95% CI: 0.8-1.4)
TKA revisions at 5-year follow-up	3.7% (95% CI: 3.1-4.4)

THA: total hip arthroplasty; TKA: total knee arthroplasty.

especially beneficial for older patients and those with more serious comorbidities.

In this study, we reported 10-year data from 2010 to 2020 from our regional Joint Replacement Registry, which included a total of 19,367 procedures. Our cost analysis showed a potential economic benefit from implementing an outpatient arthroplasty program, as reported by other authors.[38] Unfortunately, in the authors' region (South Tyrol, Italy), there is no specific DRG (Diagnosis-Related Group) reimbursement rate for outpatient arthroplasty. Furthermore, some Italian regions do not offer this type of hospitalization for hip and knee arthroplasty; in contrast, others do, but with a reduced DRG value (up to 30%), making this pathway uneconomical for many medical institutions.[39]

Nonetheless, an Italian-based preliminary report on clinical outcomes after outpatient unicompartmental knee arthroplasty (UKA) demonstrated the effectiveness of such a program.[40]

During the same period analyzed by the current authors, one North American registry and two European registries/databases reported the rate of outpatient arthroplasty procedures. An analysis of the Danish National Patient Register (DNPR) showed that from 2010 to 2020, the use of outpatient arthroplasty pathways (THA, TKA, and UKA) has significantly increased: in 2019, 5.4% of THAs, 2.8% of TKAs, and 20% of UKA were performed in ambulatory surgery centers or as outpatient procedures in classical hospital settings.[9] In contrast, in the United Kingdom (National Health Service-NHS), only 0.6% of THAs, 0.5% of TKAs, and 5.4% of UKAs were performed as outpatient procedures during 2018-2019.[10] In a similar period (2010-2017), based on data from an extensive USA database, Debbi *et al.*[41] reported a 5.3% increase in outpatient THA and a 4.7% increase in outpatient TKA.

Our analysis showed significant international variations in moving from the traditional inpatient approach to a more modern arthroplasty method. Unfortunately, economic factors remain the primary driver of this change. In the USA, the Centers for Medicare and Medicaid Services (CMS), which is the federal agency providing health coverage for more than 100 million Americans, removed the procedure "arthroplasty" from the inpatient-only list to incentivize physicians, healthcare providers, and hospitals in general to place more arthroplasty patients into outpatient care settings to lower costs.[42] A study from Denmark (a country with a universal, tax-funded public healthcare system) showed that outpatient THA and TKA performed in hospital and ambulatory surgery departments incur similar costs: compared with the cost of two-day stays, outpatient procedures are about two-thirds cheaper, provided there is no increase in complications or readmissions.[43, 44] Following this and other initiatives, the European Union is currently increasing support for the implementation of value-based health care (VBHC) across Europe.[45]

In the authors' country (Italy), a new reimbursement model was introduced at the end of 2024, following the redefinition of the Essential Levels of Assistance (LEA), which encompass the services and benefits that the National Health Service (SSN) is required to provide to all citizens.[46] Unfortunately, arthroplasty procedures remained classified as inpatient-only procedures.

Limitations of the study

This study has several limitations. The authors could only perform a narrative review of enabling technologies used in outpatient arthroplasty as the literature lacks systematic reviews and meta-analyses on how technology-based programs in outpatient arthroplasty settings might decrease readmissions, complications, and overall perioperative morbidity. Second, the regional registry analyzed has a small sample size and only includes inpatient care cases. The registry data were only partially analyzed and not fully reported, as the focus of this study was to retrospectively determine the percentage of patients eligible for outpatient arthroplasty. The potential impact of moving to an outpatient arthroplasty model was evaluated based on ASA scores and comorbidities. A direct comparison between the two arthroplasty models (inpatient and outpatient) was not possible because there was no inpatient arthroplasty subgroup.

Conclusions

The field of arthroplasty is quickly evolving due to the adoption of advanced digital technolo-

gies. The implementation of enabling technologies initially began intraoperatively: computer navigation and robotics were considered tools to enhance accuracy in implant placement during a time when one-fifth of arthroplasty patients were dissatisfied with the results. Soon after these initial applications, in efforts to enhance the value of care, advanced technologies have been effectively utilized in both the preoperative and postoperative phases of total joint replacement surgeries.

Digital screening tools, virtual care management platforms, and remote patient monitoring applications are becoming standard tools for arthroplasty healthcare providers. The adoption of enabling technologies can enhance the overall quality of the arthroplasty-related episode of care, which could be effectively shifted to an ambulatory surgery center setting, ultimately benefiting the economic aspects of the surgical event. More research is needed before outpatient arthroplasty can become a practical option, especially outside the USA, for patients undergoing hip, knee, and shoulder replacement surgery.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions

All authors contributed to the conception and design of the study. Pier Francesco Indelli, Marco Santarelli, and Roberto Picus participated in data collection. Fjorela Qordja, Marco Santarelli, and Roberto Picus participated in the statistical analysis. Pier Francesco Indelli, Michael Engl, and Fjorela Qordja participated in the interpretation of the data. Pier Francesco Indelli drafted the work. Pier Francesco Indelli, Marta Pambukhchyan, and Jeenah Gwak revised the manuscript and performed the copy editing. All authors read, reviewed, and approved the final version of the manuscript.

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