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EXPERTS' OPINION

COST-EFFECTIVE OUTPATIENT ARTHROPLASTY WORLDWIDE IN 2025

Remote patient monitoring: a giant step towards same-day arthroplasty

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ABSTRACT

The expansion of same-day discharge (SDD) total joint arthroplasty (TJA) has reshaped perioperative care, emphasizing safety, efficiency, and patient-centered recovery. Remote patient monitoring (RPM) represents a cornerstone of this transition, providing continuous assessment of clinical parameters, mobility, and pain through telemedicine, wearable devices, and smart implants. By integrating digital communication and artificial intelligence, RPM enables early detection of complications, reduces readmission, and promotes adherence to rehabilitation. This paper explores the synergistic role of telemedicine, wearable technology, and smart implants in the postoperative management of arthroplasty, discussing their technological basis, evidence of effectiveness and future prospects. Through continuous data collection and artificial intelligence (AI) -assisted analytics, RPM facilitates proactive clinical decisions and personalized care pathways. Despite challenges including regulatory approval, data integration, and patient digital literacy, the convergence of these innovations marks a paradigm shift toward precision and preventive orthopedic care.

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KEY WORDS: Telemedicine; Remote patient monitoring; Wearable electronic devices; Arthroplasty; Orthopedics.

Total joint arthroplasty (TJA) will experience tremendous growth in the next decade, with a revolutionary shift from the traditional inpatient model to fast-track and ultimately, outpatient or same-day discharge (SDD) models.[1-5] This transition is a result of innovation in surgical technology, anesthesia, and perioperative care, making it feasible to discharge the patient home within hours following surgery. Economic evaluations have shown that decreased lengths of stay can achieve up to 30% cost savings per procedure, without influencing outcome or patient satisfaction.[6-8] The outpatient approach has been associated with lower costs and complication rates equivalent to those of inpatient care when strict selection criteria are applied.[9-12]

The shift to SDD is also motivated by innovation in surgery, but by a complete shift in healthcare reimbursement models that pay for efficiency and improved outcomes. While initial SDD criteria were stringent, precluding numerous patients with significant co-morbidities or social barriers, remote patient monitoring (RPM) is now enabling a well-managed extension of such criteria. Continuous home monitoring allows physicians to treat risks such as early orthostatic intolerance, a common barrier to safe discharge.[13] The inability of regular, episodic inpatient follow-up visits to detect these short-term, high-risk episodes renders RPM an indispensable safety net. The overall goal is to maintain the rigorous standards of safety of inpatient care within the lower-cost, comfort-oriented environment of the patient's home.

Recent studies have emphasized the importance of integrating advanced digital and robotic technologies to enhance surgical precision and postoperative outcomes, supporting the progressive role of innovation in same-day arthroplasty care.[14]

As the focus shifts toward productive and patient-centered recovery, telemedicine, telerehabilitation and RPM have emerged as indispensable tools to bridge the gap between hospital and home.[15-18] Internet technologies enable systematic virtual follow-up, teaching, and immediate clinical monitoring. Studies have established that postoperative teleconsults and virtual rehabilitation classes yield outcomes comparable to regular visits, with lower readmission and unnecessary emergency assessment.[19-23] These models are complemented by mobile technology and wearable devices recording objective evidence of mobility, activity, and vital sign data, allowing clinicians to detect early deviations from the expected recovery path.[24-26]

The development of wearable and sensor-based technologies has expanded the field of postoperative monitoring. Step counters, heart rate variability, or sleep monitors now accompany self-reported symptom enumeration to provide a more comprehensive view of functional recovery.[27-30] Coupled with artificial intelligence (AI), these real-time streams of data can assist in the early detection of complications such as pain progression, orthostatic intolerance, or wound problems.[31, 32]

The convergence of telemedicine, wearable technologies, and smart implants marks a crucial milestone in the evolution of same-day arthroplasty. By enabling continuous, personalized, and data-driven postoperative follow-up, these tools transform remote patient monitoring into a true clinical ally for early complication detection and safer, patient-centered recovery at home.

Role of telemedicine and remote patient monitoring in arthroplasty

Incorporation of telemedicine into perioperative care has transformed the perioperative follow-up model for TJA. Discharge teleconsultation facilitates remote evaluation of mobility, pain, and wound healing with safety and reduced readmission.[19-23] Several prospective studies have demonstrated outcomes to be equivalent for virtual and office-based follow-up following total joint arthroplasty.[24, 25]

RPM pathways typically combine synchronous and asynchronous communication. Synchronous video visits allow for visual tracking of wound closure, range of motion, and patient ambulation in ways that are not possible with static images. Asynchronous systems, often centered on secure messaging or patient-reported outcome measures (PROMs) questionnaires, are also essential for tracking the same pain scores daily, analgesic consumption, and trend of vital signs received via connected devices.

Tan *et al*.[29] pointed out that virtual models of care not only provide clinical safety but also improve accessibility, reduce travel burden, and improve patient satisfaction. Similarly, Comodo *et al*.[20] reiterated that RPM and telehealth avenues reduced emergency visits and unplanned readmission among orthopedic high-risk patients by a significant proportion.

Above all, these systems make use of pre-established triage rules. One example is a consistent increase in a patient's resting heart rate, combined with an increasing pain score, when detected by the RPM platform. It triggers an immediate, anticipatory call from a care coordinator. Real-time data monitoring minimizes delay between complication development and clinical intervention, a secret to managing complications like deep vein thrombosis or wound hematoma.[28]

Telemedicine also holds great potential for postoperative pain management.[21] Kumar *et al.*[24] brought to light the value of virtual consultations and messaging platforms in tracking analgesic intake and early detection of uncontrolled pain. AI-based monitoring platforms can interpret patient self-reported data, pain scores, and physiological measurements to identify at-risk patients for extended recovery.[30]

Functional recovery and detection of complications through wearable devices

Wearable technology is at the core of distant rehabilitation after arthroplasty. From accelerometers to smartwatches, wearables quantify gait, steps, and mobility quantitatively and provide functional recovery measures.[15, 33]

Wearable devices go beyond simple step counts to provide a sophisticated biomechanical fingerprint of recovery. Clinically graded wearables and certified algorithms can quantify specific gait metrics, including cadence (steps per minute), stride length, and most crucially, gait symmetry. Asymmetry commonly persists for many years following TJA and is a strong predictor of diminished function and fall risk.[34] The objective quality of the data is valuable since patient self-reporting is prone to underreporting or recall bias.

Russell *et al.*[35] and Cottrell *et al.*[36] identified that telerehabilitation interventions using wearable motion sensors provide results equivalent to conventional physiotherapy.

Correia *et al.*[37] and Schreiber *et al.*[38] demonstrated that home-based rehabilitation supported by biofeedback systems is cost-effective and leads to improved compliance. These systems enable clinicians to track exercise performance and provide personalized advice through connected apps.

Wearable sensors may also act as precursors of complication. Reduced activity, reduced step counts, or altered gait symmetry may indicate pain, effusion, or mechanical instability.[34, 39] Goh *et al.*[23] validated that accelerometer activity monitoring after TKA correlates with patient-self report of recovery and Lee *et al.*[26] confirmed the validity of consumer-grade monitors in measuring postoperative physical activity.

Economic advantages have been consistently reported. Agarwal *et al.*[40] and Ferreira *et al.*[41] demonstrated that complication and satisfaction rates are similar when telemonitoring-based care pathways minimize avoidable face-to-face interactions, decreasing follow-up cost.

However, patient compliance remains the major issue. Compliance with device wear, charging and plugging in decreases after several weeks. Success of wearables depends on usability and patient activation. Sousa *et al.*[42] provided evidence that digital health literacy is a strong mediator of adherence and satisfaction, highlighting the necessity for intuitive designs, motivational feedback loops, and adequate patient education to overcome compliance challenges.

Smart and functionalized implants

The future of monitoring postoperative conditions lies in functionalized or “smart” implants capable of detecting local biochemical or mechanical change and providing diagnostic information. Van Duren *et al.*[31] defined smart implants as orthopedic implants that have sensors for mechanical load, temperature, or biochemical sensing.

Periprosthetic joint infection (PJI) is a disastrous complication, often presenting late and requiring sophisticated revision surgery.[43-47] Even though local pH decrease (acidosis) is an ongoing early indicator of bacterial metabolism in relation to PJI, new biosensing technologies are exploring multiparametric sensing.[48-52]

Next-generation devices will aim to quantify some of the PJI biomarkers, such as inflammatory cytokines (*e.g.*, interleukin-6), C-reactive protein (CRP), or specific bacterial metabolic byproducts in synovial fluid. The engineering challenge is daunting, requiring miniaturized sensors, long-term chronic biocompatibility, and, above all else, a reliable power source and long-lasting wireless communication channel capable of transmitting signals from far within the body to an external receiver.[53, 54]

The development of newer biosensing technologies makes it possible to achieve early, non-invasive diagnosis of infection biomarkers. Li *et al*.[55] developed a wireless flexible pH sensor for real-time pH measurement of the local environment around prosthetic joints. Similarly, other researchers developed flexible electrochemical sensors for continuous pH measurement at the implant interface with the view to developing early detection of infection onset.[56-58] Gosti *et al*.[50] specifically display an extremely sensitive printed pH sensor with a CB/PANI nanocomposite for Point-of-Care (POC) orthopedic infection diagnosis.

The development of "theranostic" implants that combine diagnostic and therapeutic functions is arguably the most exciting frontier. He *et al*.[48] and Gosti *et al*.[49] have just shown multifunctional "theranostic" implants, those which sense infection and release antibiotics or anti-inflammatory agents upon biochemical stimulus. Such systems can, upon the detection of a local decrease in pH (suspected diagnosis), automatically trigger localized drug delivery of therapeutic agents (initial therapy) and offer an instant, targeted, and high-dose drug delivery system to the infection site, and potentially cure the infection before it can develop a biofilm. Such technologies have the potential for earlier diagnosis, fewer revisions, and customized treatment of periprosthetic infections.[57, 58]

At the macro level, the combination of intelligent implants and wearable data produces a hybrid environment for extensive, real-time tracking of patient recovery. Bini *et al*.[32] and Hameed *et al*.[22] noted that biosensing's integration with telemedicine and AI-driven analytics could revolutionize orthopedic postoperative care.

Artificial intelligence and data integration

Machine learning (ML) models may be trained with large datasets from telemedicine platforms and wearable sensors to predict adverse outcomes. Sloan *et al*.[33] created a model to predict eligibility for discharge on the same day after TKA based on high-quality perioperative data. Patel *et al*.[27] described the potential of AI to predict infection, delayed recovery, and complications by multimodal data stream analysis.

In orthopedic telemedicine, AI-assisted systems already analyze gait, balance, and range of motion to individualize rehabilitation exercises.[30, 38] Predictive models continuously feed postoperative recovery trends, alerting clinicians to deviations before complications set in.[32] A significant, non-linear reduction in steps per day, for example, when passed through an ML model that has been trained on thousands of recovery trajectories, can alert to a future complication long before a subjective patient complaint.

These systems are a paradigm shift away from reactive towards proactive care, translating data into actionable clinical knowledge that enhances safety and efficiency. By identifying high-risk patients before the clinical presentation of a problem, orthopedic teams can rationalize pathways of care and maximize resource use.

Challenges and future directions

Nonetheless, regardless of strong evidence supporting telemedicine and wearable fusion, challenges exist. Data security, healthcare system interoperability, and biosensing implant approval by regulatory bodies are ongoing issues.[48, 49] In addition, the digital divide can serve to limit patient involvement, particularly in older or technology-unsophisticated groups.[42]

The rate of development of these technologies is well beyond traditional paradigm regulatory capabilities. Unobstructed channels to FDA or European CE-mark clearance must exist for the advanced hardware (sensors and implants) as well as the Software as a Medical Device (SaMD) that contains the AI algorithms and generates clinical alerts. The ethical and privacy concerns in collecting ongoing, highly personal biometric patient data must also be addressed. Robust data security procedures and patient consent mechanisms must exist to instill confidence.

Subsequent investigations must focus on the standardization of data protocols, validating sensor accuracy, and integrating AI-supportive decision-making into the daily workflows of clinicians. Interdisciplinary cooperation between orthopedic surgeons, biomedical engineers, and data scientists will be essential for advancing these technologies from proof-of-concept pilot tests to scalable solutions. The actual promise of this integrated ecosystem is its ability to move orthopedic care away from a one-size-fits-all approach to that of true precision medicine, where the course of each patient's recovery is optimized based on their own real-time physiological and functional parameters.

Conclusions

Remote patient monitoring has shifted from innovation to necessity in contemporary same-day arthroplasty. The combination of telemedicine, wearables, and smart implants will make it possible to detect early complications, tailor rehabilitation, and reduce healthcare spending. Telemedicine will enable continuous follow-up, wearables will monitor and guide recovery, and functionalized implants will provide real-time biochemical feedback. Furthermore, the enormous amount of data obtained from these systems is a valuable opportunity for the incorporation of artificial intelligence in the selection of patients and prediction of outcomes.

Together, these technologies place clinicians in a position to intervene earlier, reduce readmission, and improve outcomes. Surgeons need to embrace remote monitoring not as an add-on but as an essential partner to ensure safe, efficient, and patient-centered recovery in the setting of outpatient 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
Guido Bocchino and Raffaele Vitiello have given substantial contributions to the study conception and design; Pier Francesco Indelli, Guido Bocchino and Raffaele Vitiello contributed to the study supervision; Alessandro El Motassime and Luca Andriollo contributed to the literature review; Giulio Maccauro and Pier Francesco Indelli contributed to the coordination of the clinical aspects of the study; Raffaele Vitiello, Alessandro El Motassime and Luca Andriollo contributed to the data interpretation; Raffaele Vitiello contributed to the study methodological validation and to the manuscript editing; Guillermo Bonilla contributed to the study discussion; Guido Bocchino, Raffaele Vitiello, Alessandro El Motassime, and Luca Andriollo contributed to the manuscript draft, Giulio Maccauro, Pier Francesco Indelli and Guillermo Bonilla revised it critically. All authors read and approved the final version of the manuscript.

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