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Applications of machine learning in predicting complications and revision rates following total hip arthroplasty: A narrative literature review

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Abstract

Total hip arthroplasty (THA) is one of the most successful orthopaedic operations. However, the increased volume of these treatments is accompanied by an increased number of post-operative problems and revision rates. Traditional statistical models for risk stratification sometimes fail to account for complicated non-linear interactions among patient-specific variables. Thus, machine learning (ML), a subset of artificial intelligence, has been proposed as a viable method in the orthopedic literature to optimize predictive accuracy. The purpose of this narrative review was to critically appraise the current research on the application of machine learning approaches to predict short-term problems, long-term implant survival, and revision rates after THA. A literature search of relevant publications on the development and clinical validation of ML algorithms was performed in PubMed and Scopus. A review of the literature available shows that ML models, and specifically ensemble methods such as Random Forest and Gradient Boosting, have outperformed traditional logistic regression in predicting surgical site infections, dislocations, and readmissions, and have produced robust survival analyses for long-term implant failure. However, currently, these benefits are constrained by the reliance on retrospective data, algorithmic bias and the 'black-box' character of sophisticated models that limit the broad clinical integration of ML. ML has the transformative potential to tailor preoperative counseling, but additional prospective, multicenter studies using comprehensible artificial intelligence (XAI) are required to ensure safe clinical adoption.

Keywords: Machine learning, Total hip arthroplasty, Complication prediction, Revision arthroplasty, Artificial intelligence.

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Introduction

The frequency of primary and revision total hip arthroplasty (THA) is predicted to increase exponentially in the next decades due to aging populations, broadening of surgical reasons, and rising prevalence of osteoarthritis (1, 2). THA is generally considered an affordable intervention; however, post-operative complications, including surgical site infections, periprosthetic joint infections (PJI), venous thromboembolism, instability, and aseptic loosening, impose a severe physiological burden on patients and a significant financial burden on healthcare systems (3-6).

Thus, preoperative risk stratification is of utmost importance. Surgeons have traditionally employed linear scoring methods such as the American Society of Anesthesiologists (ASA) physical status classification, Charlson Comorbidity Index (CCI), and classic multivariable logistic regression models to predict adverse outcomes (7, 8). However, classic statistical methods face frequent challenges when dealing with high-dimensional data, missing variables, and the non-linear interaction between a patient's comorbidities and intra-operative factors.

In this regard, machine learning (ML) has emerged as a disruptive tool in orthopedic surgery (9, 10). ML employs algorithms that can learn iteratively from enormous volumes of data without explicit programming and is able to identify subtle clinical trends that are not detectable with standard analysis (11-14). Although the literature on this topic is rapidly increasing, the techniques and clinical applications of these models reported in different studies are significantly varied. This narrative review critically synthesizes the available literature on the application of machine learning techniques in the prediction of short-term complications, long-term outcomes, and revision rates following primary and revision THA, with emphasis on the comparison of the algorithmic performance against traditional models.

Literature Search Strategy

A narrative review of the current literature on machine learning applications for the prediction of THA outcomes. A systematic search of the literature was conducted in the PubMed and Scopus databases from inception to June 2026. Keywords and Medical Subject Headings (MeSH) were combinations of "Machine Learning", "Artificial Intelligence", "Deep Learning", "Total Hip Arthroplasty", "Complications", and "Revision". Articles were selected based on relevance to predictive modelling of postoperative adverse events, implant survivorship, and comparison of algorithm performance. Studies were included if they reported the development, internal/external validation, or clinical application of ML models in the context of THA. Studies lacking specific predictive measures (e.g., Area Under the Curve [AUC]), studies of non-orthopaedic use, expert opinion without original data, and studies in a language other than English were excluded.

Review of the Literature

To understand the current state of machine learning in THA, it is necessary to review the basic concepts, the most frequently referenced algorithms in the literature, and their specific clinical applications for predicting short- and long-term postoperative events.

1. Machine learning concepts and algorithms reported in THA literature

A paradigm change has been observed in the analysis of patients' data, moving from classical biostatistics to artificial intelligence, as demonstrated in a review of recent studies. The traditional models measure the isolated influence of one risk factor. ML algorithms, however, are effective at processing thousands of interconnected data pieces simultaneously.

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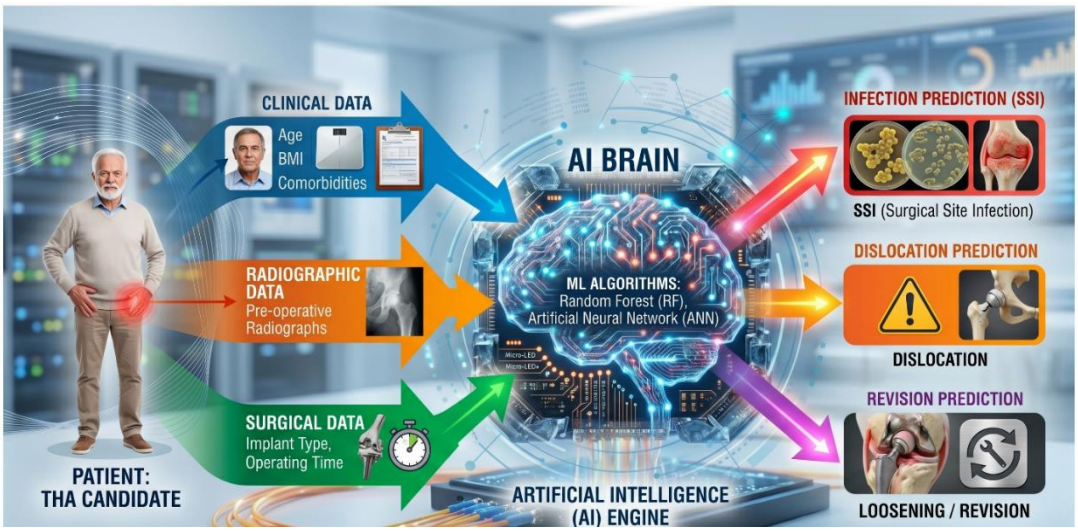

Figure 1. Schematic representation of a machine learning workflow in total hip arthroplasty. The model includes multiple preoperative, radiographic, and intraoperative variables to estimate individual risks of short- and long-term complications.

In the literature, a few well-known ML architectures are often employed in arthroplasty research. Ensemble learning approaches such as Random Forest (RF) and Extreme Gradient Boosting (XGBoost) are extremely robust to overfitting since they are able to generate several decision trees and merge their predictions (15, 16). Studies dealing with complicated inputs, e.g., preoperative radiographs for templating, commonly use Artificial Neural Networks (ANNs) and Deep Learning (DL) models (17). There is also growing research on the use of Natural Language Processing (NLP) to directly extract undocumented comorbidities from unstructured clinical notes in Electronic Health Records (EHR) (18-21).

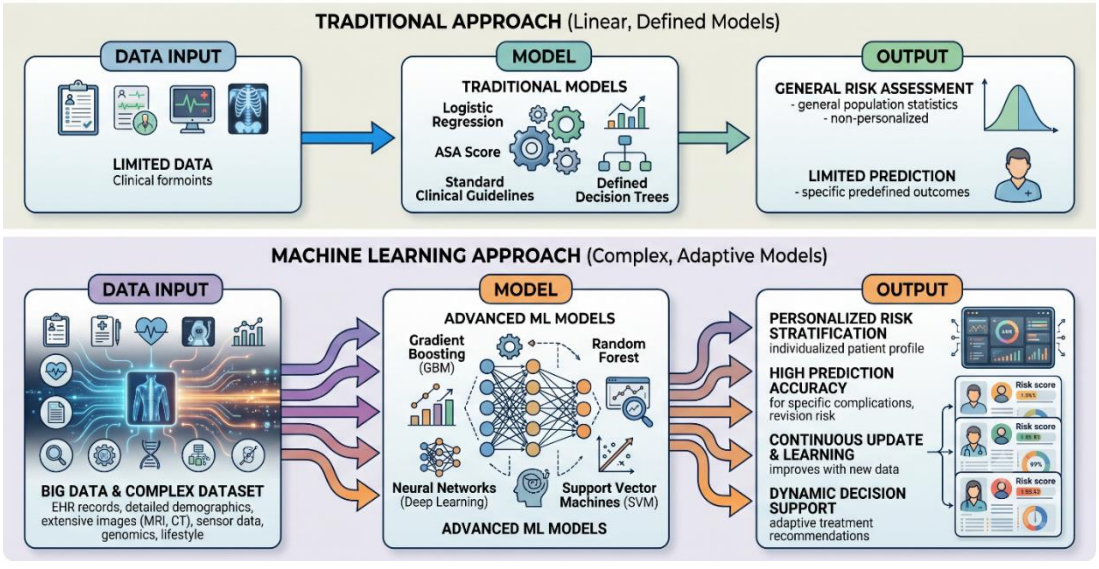

Figure 2. Machine learning versus traditional statistical modelling for risk stratification in orthopaedic surgery: from generalised scoring to personalised prediction.

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2. Literature on predicting short-term complications

The literature on predictive modeling primarily focuses on short-term adverse events (30–90 days postoperative) because they are the main drivers of extended hospital length of stay (LOS) and early readmission.

2.1. Surgical site infections and venous thromboembolism

ML algorithms that included preoperative serological markers, BMI, diabetes control metrics, and operative time have shown significantly higher sensitivity in predicting SSI than traditional logistic regression in several comparative studies (18). In a review of registry-based studies, XGBoost models are useful in weighting the non-linear risk of different levels of preoperative anemia and malnutrition. Additionally, the literature describes successful application of ML models to predict venous thromboembolism (VTE) and pulmonary embolism (PE). These models analyze national databases on a large scale to identify hypercoagulable phenotypes, as surgeons can adapt pharmacological prophylaxis protocols based on individual risk profiles (22-24).

2.2. Dislocation and readmission rates

The literature abounds with reports of postoperative dislocation as the most common cause of early revision surgery. Recent studies presenting ML frameworks have included preoperative radiographic parameters (e.g., spinopelvic mobility) with patient demographics to successfully stratify patients into high- and low-risk groups for instability (25, 26). In addition, prediction of 90-day readmission is a major theme of the recent literature on healthcare quality. Some authors have described that deep learning algorithms based on full EHR data, including socioeconomic determinants of health, have a high discriminative ability to identify patients who will need intensive outpatient support (27).

3. Literature on predicting long-term outcomes and revision rates

Mechanical stability and biological response are important factors for long-term success after THA. The literature stresses the importance of advanced capabilities of survival analysis to predict late-term failure.

Implant survivorship and aseptic loosening

Many authors criticize traditional long-term predictive models (e.g. Cox proportional hazards regression) because they assume that the hazard ratio is constant over time. This assumption is often violated in orthopaedic reality (28). To address this gap in the literature, recent studies have employed machine learning-based survival models like Random Survival Forests and DeepSurv. These studies show that ML models can update the probability of aseptic loosening over time by incorporating time-varying covariates, such as progressive osteolysis seen on serial radiographs and specific implant tribology (29).

Periprosthetic fractures and overall revision risk

Periprosthetic femoral fractures (PPFF) are becoming more prevalent, and recent publications have been dedicated to the identification of high-risk patients. ML algorithms using preoperative cortical bone thickness, femoral morphology, and stem design have been studied with promising results in predicting intraoperative and early postoperative fractures (30). Collectively, these reports would suggest that computational tools allow the surgeon to make highly individualized decisions regarding fixation strategies (e.g., cemented vs. uncemented) in frail populations.

Discussion

The literature reviewed is strongly in favor of the claim that machine learning algorithms can predict the risk of complications and revision rates after THA more accurately than traditional statistical methods. ML models demonstrate consistently higher discrimination (higher AUC) and better calibration in several studies based on

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high-dimensional registry and institutional data [18]. This increased predictive power allows for highly personalized preoperative optimization and tailored postoperative pathways.

However, critical review of the literature suggests significant barriers to routine clinical use. The most frequently mentioned limitation by several authors is the use of retrospective data. Models trained on data from institutions often suffer from algorithmic bias and poor generalizability to other demographics (31). Therefore, the literature strongly supports rigorous external validation prior to clinical deployment.

A further frequent barrier to surgical trust is the "black box" phenomenon. Surgeons are understandably hesitant to alter operative plans based on a black-box algorithm (32). To this end, recent literature points to the necessary shift towards Explainable AI (XAI) techniques such as SHAP (SHapley Additive exPlanations) values, which visually quantify the exact contribution of each patient variable to the final risk prediction (33).

The literature is clear that future studies should focus on prospective, randomized controlled trials comparing ML-augmented clinical decision-making with current standards of care.

Conclusions

The current literature indicates machine learning could revolutionize risk stratification in total hip arthroplasty with complication and revision predictions that are often more accurate than traditional statistical methods. These algorithms assist in personalized patient care, surgical planning, and resource optimization. However, retrospective designs, lack of external validation, and the inherent opaqueness of complex computational models largely limit the current literature. The future of ML in orthopedics hinges on the development of models that are highly transparent and interpretable and the rigorous prospective trials to ensure safe, equitable, and effective integration into daily surgical practice.

Guardian/patient's consent

Not Applicable.

Ethics approval

Compliant with Helsinki.

Consent

Not applicable.

Code availability

Not applicable.

Ethical statement

This study was conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Authors' contributions

SAH was responsible for the study conception, literature search, data analysis, drafting of the manuscript, critical revision for important intellectual content, and final approval of the version to be published.

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No funding has been received for this study.

Conflict of interest statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgement

None.

Data availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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