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Review Article

Artificial Intelligence in Total Hip Arthroplasty: Current Applications, Limitations and Future Perspectives — A Systematic Review

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Abstract: ***Background*:** Artificial intelligence (AI) is increasingly being integrated into total hip arthroplasty (THA), particularly in preoperative planning, predictive modeling, and postoperative imaging analysis. However, current evidence remains heterogeneous regarding methodology, validation, and clinical applicability. ***Purpose*:** To systematically review the current applications, clinical utility, limitations, and future perspectives of AI in THA. ***Methods*:** A systematic review was conducted according to PRISMA 2020 guidelines. PubMed/MEDLINE, Scopus, and Web of Science were searched for studies published between January 2015 and May 2026. Original studies evaluating AI-based applications in THA were included. ***Results*:** Thirteen studies were included in the qualitative synthesis. The principal AI application domains identified were: (1) preoperative planning and implant templating, (2) prediction of complications and functional outcomes, and (3) implant identification and postoperative imaging analysis. AI-assisted three-dimensional planning systems consistently demonstrated improved implant sizing accuracy and planning reproducibility compared with conventional templating techniques. Machine learning algorithms showed promising performance for prediction of postoperative complications, patient-reported outcomes, and periprosthetic joint infection. Deep learning-based imaging systems also demonstrated high accuracy for automated implant recognition using radiographic imaging. ***Conclusion*:** Current evidence suggests that AI-assisted technologies may improve planning accuracy, perioperative risk stratification, and workflow optimization in THA. Nevertheless, the available literature remains predominantly retrospective and heterogeneous, with limited external validation and insufficient prospective clinical evaluation.

Keywords: Artificial Intelligence, Machine Learning, Deep Learning, Total Hip Arthroplasty, Hip Replacement, Predictive Modeling.

INTRODUCTION

Total hip arthroplasty (THA) is one of the most successful procedures in orthopedic surgery, providing substantial pain relief and functional improvement in patients with end-stage hip disorders [1]. Nevertheless, complications such as implant malposition, instability, leg length discrepancy, aseptic loosening, and periprosthetic joint infection (PJI) remain important causes of postoperative morbidity and revision surgery [2]. Accurate preoperative planning and individualized surgical strategies are therefore critical for optimizing clinical outcomes and implant survivorship.

Artificial intelligence (AI) has recently emerged as a rapidly expanding field in orthopedic surgery. AI-related technologies, including machine learning (ML), deep learning (DL), neural networks, and

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computer vision, are increasingly being applied throughout the perioperative pathway of THA [3]. Current applications include AI-assisted implant templating, prediction of complications and functional outcomes, automated implant identification, and integration with advanced imaging and robotic-assisted systems.

Several studies have demonstrated improved accuracy of AI-assisted three-dimensional (3D) planning systems compared with conventional two-dimensional (2D) templating methods [4–8]. In parallel, ML algorithms have shown promising performance for prediction of postoperative complications, prolonged length of stay, patient-reported outcomes, and PJI following THA [9–11]. DL-based imaging systems have also demonstrated high accuracy for automated implant recognition using radiographic imaging, potentially facilitating revision surgery planning [12, 13].

Despite growing interest in AI-assisted technologies, the currently available literature remains heterogeneous regarding study design, validation methods, imaging protocols, and clinical applicability. Furthermore, many studies remain retrospective and primarily evaluate technical performance rather than clinically meaningful outcomes such as revision rates, implant survivorship, or patient-reported outcomes.

The purpose of this systematic review was therefore to evaluate the current applications, clinical utility, limitations, and future perspectives of AI in THA.

METHODS

Study Design

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.

Literature Search

A comprehensive literature search was performed using PubMed/MEDLINE, Scopus, and Web of Science. Studies published between January 2015 and May 2026 were screened.

The search strategy combined keywords and MeSH terms related to AI and THA, including:

- “artificial intelligence”;
- “machine learning”;
- “deep learning”;
- “neural network”;
- “computer vision”;
- “predictive model”;
- “total hip arthroplasty”;
- “total hip replacement”;
- “THA”;
- “THR”.

The PubMed search strategy was defined as follows:
(("Artificial Intelligence"[Mesh] OR "Machine Learning"[Mesh] OR
"Deep Learning"[Mesh] OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network*" OR
"computer vision" OR "predictive model*" OR "AI")
AND
("Arthroplasty, Replacement, Hip"[Mesh] OR
"total hip arthroplasty" OR "total hip replacement" OR
"hip arthroplasty" OR "THA" OR "THR"))
AND
("2015/01/01"[Date - Publication] : "2026/05/24"[Date - Publication])
Reference lists of eligible studies were manually screened to identify additional relevant articles.

Eligibility Criteria

Studies were included if they:

1. Involved patients undergoing THA;
2. Evaluated AI-based technologies, including ML, DL, computer vision, or predictive algorithms;
3. Reported outcomes related to implant templating, complication prediction, implant identification, postoperative assessment, or functional outcomes;
4. Were original studies published in English.

Review articles, editorials, conference abstracts without full text, non-THA studies, and studies evaluating conventional digital tools without AI integration were excluded.

Study Selection and Data Extraction

Two reviewers independently screened titles, abstracts, and full texts according to predefined eligibility criteria. Disagreements were resolved by consensus.

Extracted Variables Included:

- Author;
- Year of publication;
- Study design;
- Sample size;
- AI methodology;
- Clinical application;
- Reported outcomes;
- Principal findings.

Risk of Bias Assessment

Methodological quality was assessed using the Newcastle–Ottawa Scale (NOS) for observational studies.

Data Synthesis

Due to heterogeneity among included studies, a qualitative synthesis was performed. Studies were grouped according to their principal AI application domain.

RESULTS

Study Selection

The literature search identified studies from PubMed/MEDLINE, Scopus, and Web of Science. After duplicate removal and screening of titles and abstracts, potentially eligible articles underwent full-text assessment. Studies unrelated to THA, non-AI-based studies, reviews, editorials, and conference abstracts without full text were excluded.

A total of 13 studies published between 2021 and 2025 were included in the qualitative synthesis. Most studies were retrospective observational investigations with relatively limited sample sizes.

Study Characteristics

Most included studies were retrospective observational studies investigating AI applications in THA. ML and DL were the most frequently used AI methodologies.

The identified applications were classified into three principal domains:

1. AI-assisted preoperative planning and implant templating;
2. prediction of complications and functional outcomes;
3. Implant identification and postoperative imaging analysis.

AI-Assisted Preoperative Planning and Implant Templating

AI-assisted preoperative planning represented the most extensively investigated and clinically mature application domain. Huo *et al*., Ding *et al*., Chen *et al*., Wu *et al*., and Anwar *et al*., consistently reported improved implant sizing accuracy and planning reproducibility using AI-assisted three-dimensional planning systems compared with conventional two-dimensional templating techniques [4–8].

Zampogna *et al.,* additionally demonstrated that supervised ML algorithms could predict the reliability of preoperative planning based on patient-specific variables [14].

Overall, AI-assisted planning systems demonstrated favorable accuracy and reproducibility for implant templating and component positioning.

Prediction of Complications and Functional Outcomes

Several studies investigated ML-based predictive models for postoperative outcomes following THA.

Lazic *et al*., utilized registry-based data to predict postoperative complications and adverse events after primary THA [9]. Park *et al*., demonstrated promising predictive performance for failure to achieve minimal clinically important difference and substantial clinical benefit following THA [10].

Similarly, Salimy *et al.,* developed a machine learning model for prediction of PJI after primary THA [11].

Collectively, these studies demonstrated the potential utility of AI-assisted predictive systems for perioperative risk stratification and individualized patient management, although external validation remained limited in most studies.

Implant Identification and Postoperative Imaging Analysis

Karnuta *et al*., and Gong *et al*., evaluated DL-based systems for automated implant identification using radiographic imaging [12, 13]. Both studies demonstrated high classification accuracy for identification of femoral stem and acetabular implant designs.

These applications may facilitate revision surgery planning and improve postoperative implant assessment.

DISCUSSION

The present systematic review evaluated the current applications of AI in THA. The available literature demonstrates growing interest in AI-assisted technologies across multiple stages of THA management, particularly in preoperative planning, prediction of complications and functional outcomes, and automated implant identification.

Among the identified applications, AI-assisted preoperative planning currently appears to represent the most clinically advanced and reproducible field. Across the included studies, AI-assisted three-dimensional planning systems consistently demonstrated improved implant sizing accuracy and reproducibility compared with conventional two-dimensional templating techniques [4–8]. Although different AI platforms and imaging protocols were used, the overall findings remained relatively consistent.

These findings are clinically relevant because restoration of hip biomechanics, including limb length, offset, and acetabular orientation, remains essential for postoperative function and implant survivorship. Wu *et al*., notably demonstrated favorable restoration of limb length discrepancy and cup positioning using AI-assisted planning in patients with developmental dysplasia of the hip [7].

Despite encouraging results, several limitations remain. Most available studies were retrospective observational investigations with relatively limited sample sizes. In addition, many studies primarily evaluated technical accuracy rather than clinically meaningful endpoints such as revision rates, dislocation rates, patient satisfaction, or long-term implant survivorship.

Prediction of complications and postoperative outcomes represented another major application domain identified in this review. ML algorithms demonstrated promising predictive performance for adverse postoperative events, functional outcomes, and PJI following THA [9–11].

Among these applications, prediction of PJI may represent one of the most clinically relevant future uses of AI in arthroplasty. Given the substantial morbidity and economic burden associated with PJI, accurate identification of high-risk patients may improve perioperative optimization and preventive strategies.

However, most predictive models lacked robust external validation and were developed using highly specific institutional or registry-based datasets. Consequently, generalizability across different healthcare systems and patient populations remains uncertain.

Another important finding of this review was the growing role of DL-based radiographic analysis for automated implant recognition. Karnuta *et al*., and Gong *et al*., both demonstrated high accuracy for automated identification of implant designs using radiographic imaging [12, 13]. These technologies may be particularly useful in revision arthroplasty, where unavailable implant records may complicate surgical planning.

Nevertheless, the currently available evidence remains largely technical in nature. Prospective validation in routine clinical environments remains limited, and the performance of these systems in uncommon implants or poor-quality radiographs remains insufficiently investigated.

Several important barriers currently limit widespread implementation of AI-assisted technologies in THA. First, substantial heterogeneity exists regarding datasets, imaging acquisition protocols, AI methodologies, validation techniques, and reported outcome measures. Second, external validation remains insufficient in most studies. Third, many studies focus primarily on technical performance rather than clinically meaningful outcomes.

Additional concerns include data privacy, algorithm transparency, medico-legal responsibility, implementation costs, surgeon learning curves, and integration into existing surgical workflows.

The present review has several limitations. Only English-language studies were included, potentially introducing selection bias. In addition, due to heterogeneity among included studies, quantitative meta-analysis was not performed.

Future prospective multicenter studies with standardized methodologies, robust external validation, and clinically meaningful endpoints are necessary to better define the true clinical impact of AI-assisted technologies in THA.

Conclusion

Artificial intelligence represents a rapidly evolving field with promising applications throughout the perioperative management of THA. Current evidence suggests that AI-assisted technologies may improve implant templating accuracy, postoperative risk stratification, and automated implant identification.

However, the available literature remains predominantly retrospective and heterogeneous, with limited external validation and insufficient prospective clinical evaluation. Further high-quality multicenter studies are required before widespread clinical implementation can be recommended.

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