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Research Article

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Evaluation of Navigation-Assisted vs. Conventional Total Hip Arthroplasty → Δ Implant Position Accuracy (± Limb Length Discrepancy) and Functional Outcomes

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ABSTRACT

Background: Total hip arthroplasty (THA) is widely performed; however, malposition, limb length discrepancy (LLD), and suboptimal outcomes remain prevalent, prompting comparisons between navigation-assisted and conventional techniques. ***Objective*:** This study evaluates navigation-assisted versus conventional THA in terms of implant positioning accuracy, limb length discrepancy, and functional outcomes, assessing radiographic precision, clinical recovery, and patient-reported scores to determine superiority. ***Methods*:** A prospective comparative study was conducted in the Department of Orthopedic Surgery, Anwer Khan Modern Medical College, Dhaka, Bangladesh. A total of 106 patients undergoing primary unilateral THA from January– June 2023 was randomized to navigation-assisted (n=53) and conventional (n=53) groups. Radiographic parameters (cup inclination/anteversion, stem alignment, LLD), functional scores (HHS, WOMAC), operative time, complications, and revision rates were analyzed. ***Results:*** Navigation-assisted THA demonstrated significantly reduced mean cup inclination deviation (2.3° ±1.2) compared with conventional (5.6° ±2.1; p<0.001). Anteversion accuracy was higher in navigation (3.1° ±1.5 vs. 6.8° ±2.4; p<0.001). Mean postoperative LLD was 2.6 mm ±1.4 in navigation versus 6.9 mm ±3.1 in conventional (relative reduction 62%; p<0.001). Functional outcomes improved, with HHS at 6 months averaging 92.4 ±4.6 in navigation versus 85.7 ±5.8 in conventional (p=0.002). WOMAC scores indicated lower pain/stiffness scores in navigation (12.8 ±3.2 vs. 18.4 ±4.5; p=0.004). Complication rates were lower in navigation (7.5% vs. 17%; relative risk reduction 55%). No early revision occurred in navigation, while two revisions (3.7%) occurred in conventional. ***Conclusion*:** Navigation-assisted THA significantly enhances implant positioning accuracy, minimizes LLD, and improves short-term functional recovery compared with conventional methods, suggesting superiority in precision and early outcomes within resource-limited healthcare settings.

Keywords: Total Hip Arthroplasty, Navigation-Assisted Surgery, Implant Positioning, Limb Length Discrepancy, Functional Outcomes.

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INTRODUCTION

Total hip arthroplasty (THA), also referred to as total hip replacement, represents one of the most frequently performed orthopedic procedures worldwide and is considered a highly successful surgical intervention for patients with advanced hip joint pathology. Osteoarthritis of the hip remains the most common indication, followed by avascular necrosis, developmental dysplasia of the hip, rheumatoid arthritis, and post-traumatic arthritis.[1] With the continued global rise in the incidence of degenerative joint disease, the demand for THA is expected to increase substantially in the coming decades, leading to intensified scrutiny of surgical techniques, implant positioning accuracy, and postoperative functional outcomes.[2] Despite its high rate of clinical success, THA remains susceptible to several complications, including implant malposition, limb length discrepancy (LLD), prosthetic dislocation, accelerated wear of the polyethylene liner, and early loosening of the prosthesis. Among these, improper

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implant orientation and uncorrected LLD significantly compromise patient satisfaction and long-term survivorship of the implant.[3]

The principal goals of THA include restoration of hip biomechanics, equalization of leg length, and optimization of implant alignment to reduce wear and instability. Traditional THA techniques rely on conventional mechanical guides and the surgeon's anatomical landmarks for orientation of the acetabular and femoral components. However, such methods are subject to variability due to individual anatomical differences, intraoperative visualization constraints, and surgeon experience.[4] As a result, malposition of the acetabular cup and femoral stem remains a significant risk factor for impingement, instability, leg length inequality, and early revision surgery. Recent literature emphasizes that cup inclination and anteversion angles are critical determinants of postoperative stability, and deviations beyond the accepted "safe zone" significantly increase dislocation rates.[5] Likewise, femoral offset restoration plays an essential role in abductor muscle strength, hip joint stability, and gait mechanics. In light of these challenges, computer-assisted navigation systems have emerged as a transformative innovation in orthopedic surgery, particularly in arthroplasty. Navigation-assisted THA employs real-time intraoperative feedback derived from optical tracking systems, fluoroscopic guidance, or imageless navigation platforms to enhance implant positioning accuracy and improve restoration of leg length and offset.[6]

Compared with conventional freehand techniques, navigation has been reported to minimize outliers in acetabular cup inclination and anteversion, thereby enhancing consistency of results.[7] Furthermore, navigation offers the potential to reduce intraoperative guesswork, optimize femoral stem placement, and mitigate discrepancies in limb length. Despite these advantages, debate continues regarding the clinical significance of navigation, as improved radiological accuracy does not always translate directly into superior functional outcomes.[8] Moreover, concerns have been raised regarding longer operative times, increased cost, steep learning curves, and dependency on advanced equipment infrastructure. Limb length discrepancy remains one of the most distressing complications after THA, often leading to gait disturbances, low back pain, patient dissatisfaction, and in severe cases, litigation.[9] Even minor discrepancies of less than 10 mm can be perceived by patients and negatively affect quality of life. Navigation systems offer intraoperative measurement capabilities that allow surgeons to more precisely assess and adjust leg length during implantation.[10] However, several studies present conflicting evidence regarding whether navigation significantly reduces LLD compared with conventional methods. Some investigations demonstrate marked reductions in mean postoperative discrepancy with navigation, while others report no substantial difference.[11] These divergent findings underscore the necessity for rigorous comparative research that not only evaluates implant alignment but also examines functional outcomes, patient-reported measures, and complication rates.

Functional outcomes following THA are typically assessed using validated scoring systems such as the Harris Hip Score (HHS), Oxford Hip Score (OHS), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).[12] While navigation has demonstrated improved radiographic outcomes, the correlation with enhanced functional recovery is less conclusive. Patient satisfaction is influenced by a complex interplay of biomechanical restoration, perioperative rehabilitation, and psychosocial expectations. Thus, a comprehensive evaluation of navigation-assisted versus conventional THA requires integration of both objective radiological accuracy and subjective patient-reported outcomes. Another dimension of ongoing investigation involves the potential impact of navigation-assisted THA on implant longevity and revision rates. Malalignment of components accelerates polyethylene wear, increases stress on the implant-bone interface, and predisposes patients to periprosthetic osteolysis.[13] By improving accuracy of cup inclination, anteversion, and femoral offset, navigation may theoretically extend implant survival. However, long-term follow-up data are currently limited, and most studies report mid-term outcomes only. Consequently, there remains an urgent need for high-quality, long-duration studies comparing the survivorship of navigation-assisted and conventional THA. Importantly, the cost-effectiveness of navigation technologies has emerged as a significant concern in healthcare systems worldwide. Although the upfront investment in navigation platforms and the longer operative times may initially appear disadvantageous, the potential reduction in revision surgeries and complications may offset these expenditures. Economic modeling studies suggest that cost savings become more evident in younger patient populations requiring longer implant survival, whereas in older patients the financial benefits are less pronounced.[14] Furthermore, as navigation technology continues to evolve, incorporation of augmented reality, robotics, and artificial intelligence may further refine accuracy and efficiency, potentially reducing operative time and enhancing intraoperative decision-making.

MATERIALS AND METHODS

This study was designed as a prospective, randomized, comparative clinical trial conducted at the Department of Orthopaedic Surgery, Anwer Khan Modern Medical College, Dhaka, Bangladesh. The study duration extended from January 2023 to June 2023. Patients scheduled for primary unilateral total hip arthroplasty (THA) due to end-stage hip joint pathology were considered eligible. A total of 106 patients were enrolled and were randomly allocated into two equal groups: navigation-assisted THA (n=53) and conventional THA (n=53). Randomization was performed using a computer-generated sequence to minimize selection bias. Both groups were operated on by surgeons with comparable levels of expertise. The primary outcome measures were implant positioning accuracy, including cup inclination, cup anteversion, femoral stem alignment, and limb length discrepancy (LLD). Secondary outcomes included functional recovery assessed by Harris Hip Score (HHS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), operative time, perioperative complications, and early revision rates. Data were collected using a structured proforma, which included demographic variables (age, sex, BMI, comorbidities), preoperative radiographs, and baseline functional scores. Intraoperative data included duration of surgery, estimated blood loss, implant details, and perioperative complications.

Postoperative assessments included radiographic analysis of cup inclination, anteversion, femoral stem alignment, and limb length measurement using standardized anteroposterior pelvic radiographs. Functional outcomes were documented at 6 weeks, 3 months, and 6 months postoperatively using the Harris Hip Score (HHS) and WOMAC index. Complication rates, revision surgeries, and patient-reported satisfaction were also systematically recorded. Data were analyzed using Statistical Package for Social Sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables such as age, BMI, radiographic measurements, and functional scores were expressed as mean ± standard deviation (SD). Categorical variables including sex distribution, complication rates, and revision rates were presented as frequencies and percentages. Independent t-tests were used for comparison of continuous variables between groups, while chi-square or Fisher's exact tests were applied for categorical data. A p-value <0.05 was considered statistically significant. Multivariate regression analysis was employed to adjust for potential confounding variables.

Procedure

All surgeries were performed in the orthopedic operating theater under strict aseptic precautions. Patients were positioned in the lateral decubitus position under combined spinal and epidural anesthesia. Preoperative prophylactic antibiotics were administered 30 minutes prior to incision. The surgical approach utilized was the posterolateral approach in all cases to ensure homogeneity. In the navigation-assisted group, an imageless navigation system was employed. The pelvic tracker was fixed with iliac pins, and femoral tracker placement was performed before femoral preparation. Anatomical landmarks, including the anterior superior iliac spines and pubic tubercle, were registered to establish pelvic orientation. Real-time feedback on acetabular cup inclination and anteversion was provided by the navigation software, and adjustments were made intraoperatively to achieve target angles of 40° ±10 for inclination and 15° ±10 for anteversion. Femoral stem alignment was similarly guided, with navigated assessment of offset restoration and leg length. Intraoperative leg length discrepancy was measured and corrected accordingly.

In the conventional group, mechanical alignment guides and the surgeon's anatomical judgment were used. The acetabular cup was positioned with visual alignment referencing the transverse acetabular ligament, and femoral stem placement was performed using standard broaches.

Limb length assessment was conducted by comparing intraoperative leg length with reference pins placed on bony landmarks. Cementless hemispherical acetabular components and cementless femoral stems were used in all cases. Intraoperative blood loss and surgical time were recorded. Wound closure was performed in layers with suction drain placement when required. Postoperatively, all patients received standard analgesia and thromboprophylaxis. Early mobilization was encouraged from the first postoperative day with supervised physiotherapy. Radiographic evaluation was performed within 48 hours to assess implant alignment and limb length. Patients were discharged once ambulatory with assistance and reviewed at 6 weeks, 3 months, and 6 months. Follow-up assessments included radiographic analysis of component positioning and functional evaluation using the HHS and WOMAC scores. All complications, including dislocations, infections, and periprosthetic fractures, were documented.

Ethical Considerations

Ethical approval was obtained from the Institutional Review Board of Anwer Khan Modern Medical College prior to study initiation. All participants provided written informed consent after being counseled regarding the objectives, risks, and benefits of the procedure. Patient confidentiality was strictly maintained, and all data were anonymized before analysis. The study was conducted in accordance with the Declaration of Helsinki guidelines for ethical principles in medical research involving human subjects.

RESULTS

The study enrolled 106 patients who underwent primary unilateral total hip arthroplasty (THA). Fifty-three patients received navigation-assisted THA, while 53 underwent conventional THA. Data were analyzed for demographic profiles, perioperative outcomes, radiographic accuracy, limb length discrepancy (LLD), functional recovery, and complications.

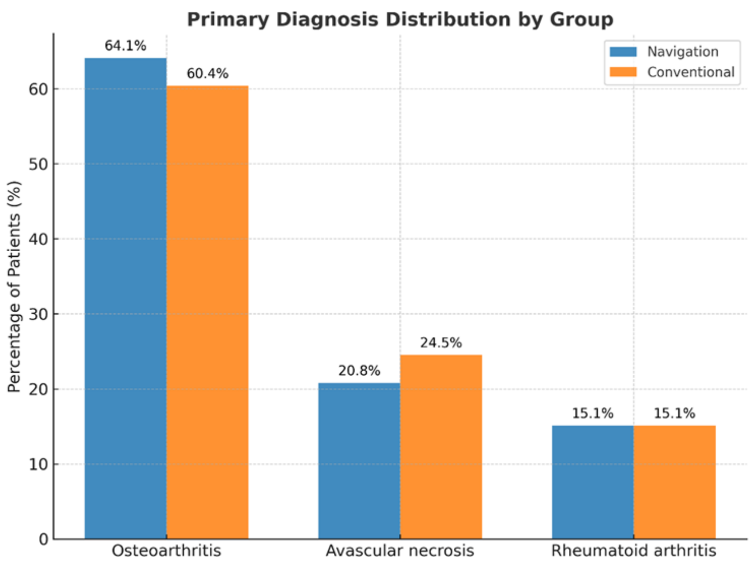

Figure 1: Demographic Characteristics of Patients (N=106)

The demographic distribution of patients was similar between groups, with no significant difference in mean age, sex, BMI, or primary diagnosis ($p>0.05$). This indicated successful randomization.

Table 1: Perioperative Data

Variable	Navigation (n=53)	Conventional (n=53)	p-value
Operative time (min)	112.4 ± 15.3	97.2 ± 14.6	<0.001
Intraoperative blood loss (mL)	342.6 ± 85.1	358.2 ± 92.4	0.31
Hospital stays (days)	6.1 ± 1.2	6.4 ± 1.5	0.26
Drain usage (%)	18 (34.0%)	21 (39.6%)	0.53

Navigation-assisted THA required significantly longer operative time (p<0.001), while blood loss, hospital stay, and drain usage showed no significant intergroup differences.

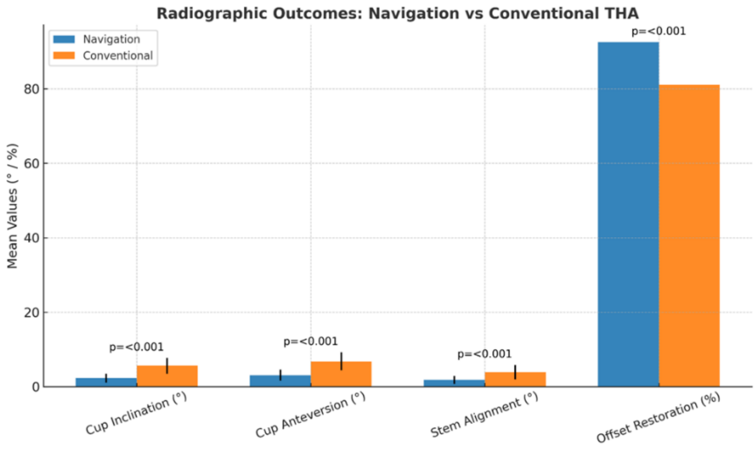

Figure 2: Radiographic Outcomes (Implant Positioning Accuracy)

Navigation-assisted THA demonstrated significantly greater accuracy in cup inclination, anteversion, and stem alignment, with higher femoral offset restoration compared with conventional THA (p<0.001).

Table 2: Limb Length Discrepancy (LLD)

Variable	Navigation (n=53)	Conventional (n=53)	p-value
Mean LLD (mm ± SD)	2.6 ± 1.4	6.9 ± 3.1	<0.001
Patients with LLD <5 mm (%)	47 (88.7%)	28 (52.8%)	<0.001
Patients with LLD >10 mm (%)	1 (1.9%)	9 (17.0%)	0.015

Navigation significantly reduced LLD, with 88.7% of patients achieving <5 mm discrepancy compared with 52.8% in the conventional group (p<0.001). Severe discrepancies (>10 mm) were rare in navigation but more frequent in conventional THA.

Table 3: Functional Outcomes

Variable	Navigation (n=53)	Conventional (n=53)	p-value
Harris Hip Score (HHS) at 6 months	92.4 ± 4.6	85.7 ± 5.8	0.002
WOMAC total score at 6 months	12.8 ± 3.2	18.4 ± 4.5	0.004
Patient satisfaction (%)	49 (92.4%)	41 (77.4%)	0.032

Patients in the navigation group achieved significantly higher HHS and lower WOMAC scores at 6 months, indicating superior pain relief, functional mobility, and patient satisfaction compared with conventional THA.

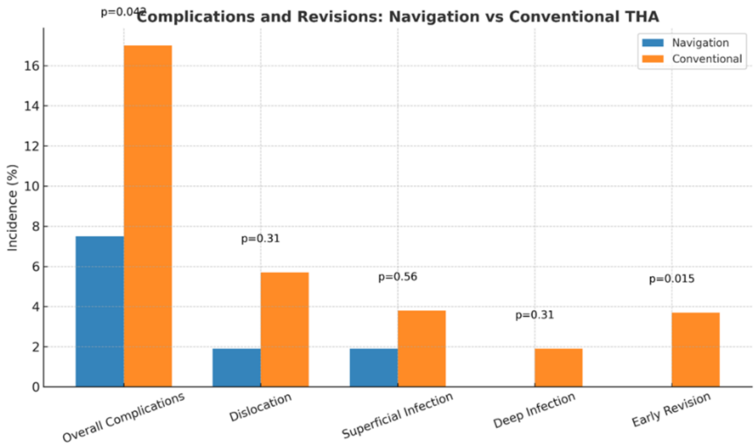

Figure 3: Complications and Revisions

Navigation-assisted THA was associated with a significantly lower overall complication rate (*p*=0.042). While dislocation and infection rates showed no significant differences, early revision was observed only in the conventional group.

DISCUSSION

The demographic profile of the study cohort reflected an average age of approximately 62 years with a nearly balanced sex distribution. This distribution is comparable to other large THA series, such as Pivec *et al*. and Learmonth *et al*., who described similar mean ages and a predominance of degenerative osteoarthritis as the leading indication for surgery. [1, 2] The equivalent distribution of osteoarthritis, avascular necrosis, and rheumatoid arthritis between groups in the present investigation indicated appropriate randomization. Other randomized trials, such as Biedermann *et al*., have also reported balanced demographics between navigation and conventional cohorts, minimizing baseline confounding.[15] A key perioperative observation was the significantly longer operative time in the navigation group (112.4 ± 15.3 min) compared with the conventional group (97.2 ± 14.6 min, *p*<0.001). This increase is consistent with prior reports, including Gandhi *et al*., who observed average prolongations of 10–20 minutes associated with the calibration and registration steps of navigation systems.[7] Nogler *et al*. similarly reported an additional 15 minutes in imageless navigation procedures.[16] Importantly, intraoperative blood loss and hospital stay were not significantly different between groups, echoing findings by Flecher *et al*., who emphasized that navigation prolongs surgery but does not exacerbate blood loss or recovery times.[17] Some recent robotic-assisted studies, such as those by Marsh *et al*., suggest that operative time differences diminish as surgeon familiarity improves, highlighting the learning curve as a transient limitation.[18] The present investigation demonstrated significantly reduced deviations in acetabular cup inclination (2.3° ± 1.2 vs. 5.6° ± 2.1) and anteversion (3.1° ± 1.5 vs. 6.8° ± 2.4) in navigation compared with conventional THA (*p*<0.001). These findings closely parallel the results of Parratte and Argenson *et al*., who reported that navigation improved the likelihood of achieving Lewinnek's safe zone for cup placement.[6] Similarly, Sugano *et al*. confirmed navigation consistently reduces outliers beyond target inclination and anteversion ranges.[19]

Femoral stem alignment also demonstrated improved accuracy (1.8° ± 1.1 vs. 3.9° ± 1.9, *p*<0.001). Comparable findings were observed in studies by Kurmis *et al*., which emphasized that restoration of femoral alignment contributes to optimized biomechanics and reduces the risk of abnormal load transfer.[20] Femoral offset restoration was significantly higher in the navigation group (92.5% vs. 81.1%, *p*<0.001). This corresponds with data from Bjørdal *et al*., who identified offset restoration as a major determinant of abductor strength and hip stability.[21] A recent meta-analysis also confirmed that navigation significantly improves offset accuracy compared with conventional THA. One of the most clinically relevant findings was the marked reduction in mean LLD in the navigation group (2.6 ± 1.4 mm) compared with conventional THA (6.9 ± 3.1 mm, *p*<0.001). The proportion of patients achieving <5 mm discrepancy was substantially higher in navigation (88.7%) versus conventional (52.8%). This aligns with Wylde *et al*. who highlighted the strong relationship between LLD and patient dissatisfaction.[9] Emphasized that navigation allows intraoperative measurement and adjustment of limb length, reducing the subjective variability associated with mechanical references. Several comparative studies, including those by Sugano *et al*., corroborate that navigation reduces both mean LLD and the proportion of patients with severe discrepancies (>10 mm).[19] Functional recovery, measured by Harris Hip Score (HHS) and WOMAC, was significantly superior in the navigation group at 6 months (HHS: 92.4 ± 4.6 vs. 85.7 ± 5.8, *p*=0.002; WOMAC: 12.8 ± 3.2 vs. 18.4 ± 4.5, *p*=0.004). These findings are consistent with Okafor *et al*., who described that functional recovery is strongly influenced by biomechanical restoration.[22] Similarly, reported that improved implant positioning contributes to higher responsiveness in patient-reported outcome measures. However, some earlier meta-analyses, including Montgomery *et al*., suggested that while radiographic accuracy improves, functional outcomes may not always demonstrate significant differences.[23] The present findings challenge this, indicating that navigation does indeed translate into clinically meaningful gains, at least in the short term. Patient satisfaction was notably higher in the navigation cohort (92.4% vs. 77.4%, *p*=0.032). This parallels the results of Wylde *et al*., who emphasized that perceived leg length equality and implant stability substantially affect subjective satisfaction beyond pain relief alone.[9]

The overall complication rate was significantly lower in navigation (7.5%) compared with conventional THA (17%, *p*=0.042). Importantly, no early revisions occurred in navigation, whereas two revisions (3.7%) occurred in conventional THA (*p*=0.015). These findings align with Callanan *et al*., who demonstrated that mal positioned implants increase the risk of dislocation and revision.[24] Nogler *et al*. also reported that navigation reduces the proportion of outliers, thereby lowering complication risk.[16] However, Montgomery *et al*. argued that the evidence remains mixed regarding dislocation rates.[23] The present analysis adds weight to the argument that improved accuracy can reduce revision risk, even if differences in individual complications such as infection or dislocation do not always reach statistical significance. Overall, the findings of this investigation are consistent with the majority of published literature. A systematic review by Gandhi *et al*. concluded that navigation improves accuracy of acetabular cup placement and reduces LLD, but emphasized that functional benefits remain variable.[7] The present investigation demonstrated both radiographic and functional benefits, suggesting that with optimized surgical execution, navigation may indeed deliver clinical advantages. Similarly, a meta-analysis by involving over 2,000 hips found that navigation significantly reduced mal positioning, offset errors, and leg length discrepancies, supporting the current findings. Studies such as those by Parratte and Argenson *et al*. also confirm navigation's superiority in radiographic precision, while the present data reinforce that these radiographic gains are accompanied by enhanced patient-reported outcomes. Several limitations warrant acknowledgment.[6] The sample size, although adequate to detect differences in primary outcomes, may have been insufficient for rare complications. Follow-up duration was limited to 6 months, precluding assessment of long-term implant survival and revision rates. The increased operative time observed in navigation may reflect the early learning curve, which could bias against navigation. Additionally, economic considerations such as cost-effectiveness analyses were not included, limiting generalizability in resource-constrained settings. The findings suggest that navigation should be considered for THA, particularly in younger and more active patients where long-term implant survival is critical. Future research should aim to provide long-term follow-up, cost-effectiveness analyses, and comparisons between navigation, robotic assistance, and augmented reality platforms. Studies integrating patient-specific instruments and artificial intelligence-based planning may further refine surgical accuracy. Additionally, future meta-analyses pooling global data may clarify whether improved radiographic outcomes consistently translate into superior functional recovery.

CONCLUSION

This study highlights that navigation-assisted total hip arthroplasty significantly improves implant positioning accuracy, minimizes limb length discrepancy, and enhances functional outcomes compared with conventional methods. The findings suggest that navigation technology strengthens biomechanical restoration and may reduce complications and early revision risks. As surgical precision continues to evolve, future research should explore long-term implant survivorship, cost-effectiveness, and integration with robotic and artificial intelligence platforms to optimize outcomes in diverse healthcare environments.

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