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Digital inclinometer-guided acetabular cup positioning in total hip arthroplasty: A prospective observational study

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Abstract:
Proper acetabular cup alignment during total hip arthroplasty (THA) is essential to reduce instability, impingement, wear and loosening, but advanced navigation systems are often unavailable because of their cost and limited accessibility. This prospective study evaluated 30 patients undergoing THA between May 2024 and April 2026 using a dual-axis digital inclinometer for intraoperative cup inclination and post-operative radiographic inclination and Harris Hip Score at 6 months were assessed. Post-operative radiographs showed that 27 of 30 hips (90%) were within the Lewinnek safe zone and the mean post-operative inclination angle was significantly lower in the safe group than in the unsafe group (42.34 ± 3.00° vs. 55.91 ± 4.26°, $p < 0.05$). Patients with cup placement within the safe zone had better Harris Hip Scores (86.22 ± 8.64 vs. 81.00 ± 6.08), while a weak positive correlation was observed between intraoperative and post-operative inclination measurements ($r = 0.360$, $p = 0.060$). Thus, digital inclinometer-assisted cup placement is a simple, practical and cost-effective technique that may improve acetabular cup alignment during THA, particularly in centres without navigation facilities.

Keywords: Digital inclinometer; total hip arthroplasty (THA); acetabular cup inclination; lewinnek safe zone; hip replacement

Background:
Total hip arthroplasty (THA) is a commonly performed procedure for patients with severe hip disease, offering good pain relief and improvement in daily activities and joint function. Advancements in implant design, biomaterials and surgical techniques have significantly improved implant longevity and patient satisfaction. Despite these developments, complications such as dislocation**,** impingement**,** accelerated wear and early loosening continue to occur, often secondary to improper acetabular cup positioning **[1, 2]**. Acetabular cup orientation primarily depends on inclination and anteversion. Lewinnek *et al.* described the concept of a "safe zone" consisting of 30°C–50°C inclination and 5°C–25°C anteversion, which is believed to reduce the risk of post-operative instability and dislocation. Accurate cup placement during surgery remains technically challenging. Factors such as patient positioning **[3],** pelvic tilt **[4],** spinal alignment **[5],** surgical approach **[6],** obesity and surgeon experience **[7]** can significantly influence final implant orientation. Conventional mechanical alignment guides depend on assumptions regarding patient positioning and may not account for intraoperative pelvic movement, resulting in inaccuracies **[8].** Computer-assisted navigation systems have been introduced to improve the precision of acetabular component positioning. Although these systems improve accuracy, their widespread use is limited because of increased operative time, cost and the requirement for specialized equipment and training **[9, 10]**. Therefore, it is of interest to evaluate the practical utility and clinical applicability of a digital inclinometer as an intraoperative guide during THA.

Materials and Methods:
This prospective observational study was conducted in the Department of Orthopaedics at Netaji Subhash Chandra Bose Medical College Jabalpur, Madhya Pradesh, India between May 2024 and April 2026. A total of 30 patients undergoing total hip arthroplasty (THA) were included in the study. Institutional Ethics Committee approval was obtained before commencement of the study and informed written consent was obtained from all patients (IEC Approval No: 2024/4539-112).

Inclusion criteria:
[1] All patients undergoing THA.

Exclusion criteria:
[1] Patients medically unfit for surgery.
[2] Patients unwilling to participate in the study.

Pre-operative assessment:
Preoperative pelvic radiographs were evaluated for native acetabular orientation and surgical planning.

Surgical technique:
All surgeries were carried out by a single experienced surgical team through the posterior approach with the patient placed in the lateral decubitus position. Prior to acetabular reaming, the operating table alignment was calibrated to zero degrees using the digital inclinometer. During placement of the acetabular component, intraoperative inclination was measured using a dual-axis digital inclinometer. After appropriate calibration with reference to the table position, the inclinometer was mounted on the cup impactor. The desired cup inclination was planned within the Lewinnek safe zone parameters. Adjustments in component orientation were made during impaction according to the inclinometer measurements. After final implantation, hip stability and range of motion were evaluated clinically before closure of the surgical wound.

Post-operative assessment:
Post-operative radiographs were obtained using standardized anteroposterior pelvis views. Acetabular cup inclination was measured radiographically using the inter-ischial tuberosity method and compared with intraoperative inclinometer values. Patients were categorized into safe zone (30°C-50°C) and unsafe zone groups (<30°Cor >50°C) according to post-operative cup inclination measurements. Clinical outcome assessment was performed using the Harris Hip Score at 6 months follow-up

visits. Patients were evaluated clinically and radiologically for complications such as dislocation, loosening, infection, or implant-related problems.

Statistical analysis:

All recorded data were compiled and analyzed using SPSS statistical software. Continuous variables were summarized as mean values along with standard deviations. Prior to statistical testing, the normality of data distribution was examined to determine the suitability of parametric methods. Comparisons between the study groups were carried out using the Student's t-test. The association between intraoperative inclinometer measurements and post-operative radiographic inclination angles was assessed using Pearson's correlation coefficient. Statistical significance was defined at a p-value of less than 0.05.

Results:

Thirty patients who underwent total hip arthroplasty (THA) were included in the present study. The majority of patients belonged to the 31–40 years age group. There was a male predominance, with males comprising 66.7% of cases and females 33.3%. Avascular necrosis was the leading indication for surgery, while osteoarthritis and fracture-related sequelae were less common indications **(Table 1)**. The safe zone group (n = 27) demonstrated significantly lower mean post-operative inclination angles compared with the unsafe group (42.34 ± 3.00°C vs 55.91 ± 4.26°C, $p < 0.05$). Intraoperative inclination measurements demonstrated limited variation between groups, suggesting consistent intraoperative angular guidance during cup placement. At 6 months follow-up, patients in the safe zone had better Harris Hip Scores compared with the unsafe group **(Table 2).** Overall, acetabular component placement was within the Lewinnek safe zone in 90% of cases. Post-operative dislocation occurred in one patient only. Statistical analysis using Fisher's exact test did not show a significant relationship between cup position and occurrence of dislocation. Pearson correlation analysis showed a weak positive correlation between intraoperative and post-operative inclination angles ($r = 0.360$, $p = 0.060$). Despite the weak statistical correlation, the study showed a high safe zone achievement rate with acceptable early functional outcomes **(Figure 1, Figure 2)**.

Table 1: Baseline demographic and clinical details of the study group (N = 30)

Parameter	Category	n (%)
Age group (years)	20 to 30	8 (26.7%)
	31 to 40	9 (30.0%)
	41 to 50	6 (20.0%)
	51 to 60	2 (6.6%)
	>60	5 (16.7%)
Gender	Male	20 (66.7%)
	Female	10 (33.3%)
Side of Surgery	Right hip	18 (60.0%)
	Left hip	12 (40.0%)
Indication for THA	Avascular necrosis	22 (73.3%)
	Osteoarthritis	2 (6.7%)
	Femoral neck fracture	2 (6.7%)
	Revision THA following cement spacer placement	2 (6.7%)
	Intertrochanteric fracture of femur	1 (3.3%)
	Post Girdlestone arthroplasty	1 (3.3%)

Table 2: Comparison of clinical and radiological outcomes between safe and unsafe cup position groups

Parameter	Safe cup position (n = 27) Mean ± SD	Unsafe cup position (n = 3) Mean ± SD	p
Preoperative cup inclination (°C)	41.89 ± 4.05	49.50± 2.96	**0.026**
Intraoperative cup inclination (°C)	43.35 ± 1.98	44.50 ± 0.87	**0.335**
Post-operative cup inclination (°C)	42.34 ± 3.00	55.91 ± 4.26	**0.026**
Harris Hip Score at 6 months	86.22 ± 8.64	81.00 ± 6.08	**0.331**

Table 3: Comparison of present study with van Duren and Goldstein studies

Type of Study	Sample Size	Main Method	Mean inclination achieved	Safe Zone accuracy	References
Prospective observational study	30 hips	Digital inclinometer-assisted THA	Post-operative inclination: 42.34°C±3.00 in safe group	90% (27/30) within safe zone	Present study
Systematic review	More than 600 hips	Review of inclinometer studies	Most studies showed inclination around target range with reduced SD	Majority studies showed improved safe-zone placement	**[11]**
Non-randomized controlled trial	223 hips	Inclinometer vs control	Inclinometer: 43.9°C vs control: 41.5°C	No significant improvement	**[12]**

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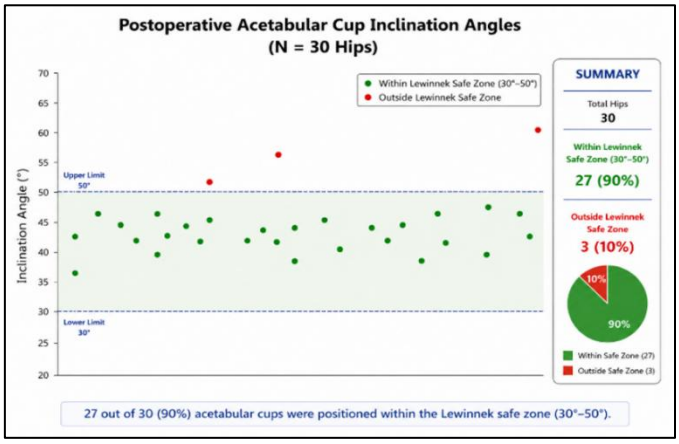


Figure 1: Distribution of acetabular cups within the Lewinnek safe zone

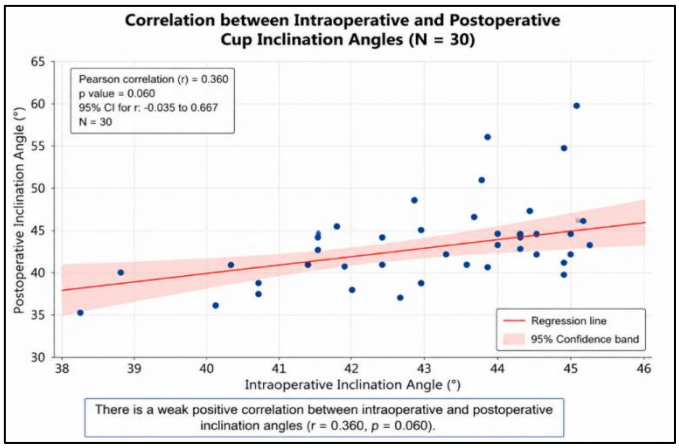


Figure 2: Correlation between intraoperative and post-operative inclination angles

Discussion:

Accurate orientation of the acetabular component is a key factor influencing the success of total hip arthroplasty (THA). Malposition of the cup can lead to complications such as instability, impingement, accelerated polyethylene wear and eventual loosening of the implant. In the present study, the majority of acetabular cups were positioned within the Lewinnek safe zone using guidance from a digital inclinometer. The average post-operative inclination angle was significantly lower in the safe zone group compared with the unsafe group (42.34 ± 3.00°C versus 55.91 ± 4.26°C, $p < 0.05$). In addition, patients with cup placement inside the safe zone showed superior Harris Hip Scores at follow-up evaluation. Comparable findings have also been described in earlier studies by van Duren *et al.*, who observed that inclinometers may improve the consistency of acetabular cup inclination compared with freehand techniques. Their review highlighted that digital inclinometers are inexpensive, portable and capable of producing measurements correlating with post-operative radiographic values **[11].** Similar observations were noted in the present study, particularly in technically demanding cases with altered hip anatomy. However, Goldstein *et al.* reported that inclinometer use did not significantly improve acetabular component positioning compared with conventional techniques. They suggested that factors such as pelvic movement, patient positioning and surgical variability may still influence final cup orientation **[12].** Yi *et al.* reported reduced anteversion measurement bias with a digital protractor **[13],** while Nguyen *et al.* reported a mean acetabular inclination of 41.9° using the transverse acetabular ligament as an intraoperative reference **[14].** Singh *et al.* reported a post-operative inclination of 42.7° ± 5.31° and no significant association with HHS, which is comparable to our finding of no significant difference in 6-month HHS (86.22 ± 8.64 vs. 81.00 ± 6.08, p=0.331) **[15].** Similarly, Kashayi-Chowdojirao *et al.* showed acceptable agreement between smartphone-assisted intraoperative and CT-based measurements, supporting the feasibility of low-cost digital measurement techniques **[16].** Overall, these findings are consistent with our results and support the use of a digital inclinometer as a simple intraoperative adjunct for acetabular cup positioning**.** One possible explanation for the weak correlation between intraoperative and post-operative measurements is the influence of intraoperative pelvic movement and radiographic projectional variation. In addition, subtle changes during final cup impaction may alter the final orientation despite acceptable intraoperative alignment**.** The present study showed that digital inclinometer-assisted acetabular cup placement resulted in a high rate of Lewinnek safe zone achievement with satisfactory early radiological and functional outcomes following THA. Although Pearson correlation analysis showed only a weak positive correlation between intraoperative and post-operative inclination measurements, the inclinometer still provided consistent intraoperative angular guidance during cup implantation. The weak correlation observed may be attributable to factors such as intraoperative pelvic movement, variability in patient positioning, final cup impaction and projectional differences in post-operative radiographic assessment. Nevertheless, the technique was found to be simple, inexpensive, portable and easy to integrate into routine operative workflow. Therefore, digital inclinometers may serve as practical and cost-effective adjuncts for assisting intraoperative acetabular cup positioning during THA, particularly in resource-constrained centres where advanced computer-assisted navigation systems are not readily available. The present study evaluates a simple, practical and low-cost intraoperative technique that may be easily incorporated into routine arthroplasty practice. The prospective study design standardized surgical approach and clinically relevant radiographic assessment strengthen the practical applicability of the findings, particularly in resource-constrained settings. This study included a limited number of patients with short-term follow-up. Cup anteversion was not assessed separately and post-operative evaluation was based on plain radiographs rather than CT scans. The small number of patients in the unsafe zone group may limit the strength of comparative statistical analysis. However, the findings still support the

usefulness of digital inclinometer-assisted cup positioning as a practical and affordable intraoperative aid during THA.

Conclusion:

Digital inclinometer-assisted cup placement is a simple, inexpensive and practical intraoperative technique that may improve the accuracy and consistency of acetabular cup positioning during THA. The present study demonstrated a high rate of Lewinnek safezone placement with acceptable early functional outcomes. Although correlation between intraoperative and post-operative inclination measurements was weak, digital inclinometers may serve as useful adjuncts in centres where advanced navigation systems are unavailable or financially impractical.

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