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Original Research Article

Acetabular Cup Positioning in Primary Routine Total Hip Arthroplasty: A Prospective Observational Study of 100 Patients from a Tertiary Care Centre in Bihar, India

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Abstract

Background: Accurate acetabular cup orientation is a modifiable technical determinant of stability, impingement-free range of motion, wear, and patient-reported recovery after total hip arthroplasty (THA). Although conventional safe zones remain widely used, contemporary concepts emphasize functional cup position, combined anteversion, pelvic tilt, and spinopelvic mobility.

Aim: To evaluate radiographic accuracy of acetabular cup positioning in routine primary THA and to analyze its association with early clinical and radiographic outcomes.

Methods: This prospective observational study included 100 consecutive patients undergoing primary routine THA at Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India, from 5 April 2025 to 31 March 2026. Cup inclination and anteversion were measured on standardized postoperative anteroposterior pelvic radiographs and cross-table lateral/modified radiographic assessment where available. Target-zone status was defined using a pragmatic Lewinnek-based radiographic zone: inclination 30°–50° and anteversion 5°–25°. Functional recovery, complications, and radiographic outcomes were assessed up to 6 months.

Results: Mean cup inclination was 41.6 ± 6.2° and mean anteversion was 18.9 ± 7.5°. Inclination, anteversion, and combined target-zone compliance were achieved in 88.0%, 83.0%, and 76.0% of patients, respectively. Patients within the target zone had superior 6-month Harris Hip Score (88.6 ± 7.9 vs. 81.2 ± 10.6; $p<0.001$) and Forgotten Joint Score-12 (76.8 ± 12.4 vs. 67.1 ± 14.8; $p=0.002$). Outside-zone placement was associated with higher limp, impingement symptoms, clinically relevant leg-length discrepancy, and numerically higher instability events.

Conclusion: In routine primary THA, conventional radiographic cup target-zone achievement was feasible in nearly three-fourths of cases and was associated with better early function. However, residual outliers and instability despite apparently acceptable placement support systematic preoperative planning, intraoperative pelvic control, and selective functional/spinopelvic assessment.

Keywords: acetabular cup, total hip arthroplasty, cup inclination, cup anteversion, Lewinnek safe zone, spinopelvic mobility, Harris Hip Score.

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Introduction

Total hip arthroplasty (THA) is among the most successful reconstructive procedures in modern orthopaedics, but its durability and functional success remain strongly dependent on reproducible restoration of hip biomechanics. Among surgeon-controlled variables, acetabular component positioning is especially important because cup orientation influences impingement-free range of motion, edge loading, polyethylene wear, liner fracture risk, iliopsoas irritation, instability, and long-term survivorship [1,2]. The classical Lewinnek safe zone, described as 40° ± 10° of inclination and 15° ± 10° of anteversion, provided a practical radiographic target and remains deeply embedded in surgical teaching [3]. However, contemporary registry analyses, systematic reviews, and dislocation studies have shown that a static universal safe zone does not fully prevent

instability, because dislocation is multifactorial and affected by surgical approach, femoral version, soft-tissue tension, head size, offset, lumbopelvic motion, neuromuscular control, and patient-specific sagittal balance [4,5].

The evolving concept is therefore not merely whether the cup lies inside a fixed coronal-plane window, but whether the acetabular component is positioned appropriately for the individual patient. Combined anteversion models integrate cup and femoral stem version to reduce prosthetic impingement [6]. Functional safe-zone concepts further consider that the pelvis changes orientation between standing, sitting, and deep flexion; a cup that appears satisfactory on a supine anteroposterior radiograph may function as relatively retroverted or excessively anteverted depending on pelvic tilt and spinopelvic stiffness [7,8]. This is clinically relevant in older THA populations, many of whom have degenerative lumbar disease, flatback deformity, prior lumbar fusion, or reduced pelvic mobility. Recent literature has therefore emphasized standing and sitting lateral spinopelvic radiographs, CT-based planning, navigation, robotics, and patient-specific targets in selected cases [8-11].

Despite these advances, most primary THA procedures in resource-constrained settings continue to be performed using conventional mechanical alignment guides, surgeon experience, preoperative templating, and postoperative radiographic audit. This makes local prospective data important. Indian tertiary hospitals manage a heterogeneous THA population that includes primary osteoarthritis, avascular necrosis, fracture sequelae, inflammatory arthritis, dysplasia spectrum, and post-infective or post-traumatic deformity. Pelvic positioning on the operating table, obesity, acetabular osteophytes, contractures, and femoral morphology can all introduce errors between intended and achieved cup orientation. In addition, the reliability of plain radiographic measurements depends on pelvic rotation, beam centering, and identification of cup margins, yet radiographs remain widely used because they are inexpensive, accessible, and clinically interpretable [12].

The present study was designed to evaluate acetabular cup positioning in routine primary THA at Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India. The primary objective was to determine the proportion of cups placed within a conventional radiographic target zone for inclination and anteversion. Secondary objectives were to describe outlier patterns, identify patient and anatomical factors associated with outside-zone placement, and correlate cup-position status with early functional outcomes and complications. The study intentionally focuses on routine primary THA rather than highly selected complex reconstruction, because small but preventable deviations in cup position during everyday arthroplasty can influence satisfaction, limp, impingement, instability, and revision burden. By combining practical radiographic measurements with early clinical outcomes, this article aims to provide a clinically usable audit framework and to position conventional cup placement within the newer paradigm of functional and patient-specific acetabular alignment.

Materials and Methods

This prospective observational study was conducted in the Department of Orthopaedics, Jawaharlal Nehru Medical College and Hospital, Bhagalpur, Bihar, India, from 5 April 2025 to 31 March 2026. A total of 100 consecutive adult patients who underwent primary routine THA during the study period were included after institutional approval and written informed consent. Patients undergoing revision THA, tumour reconstruction, acute acetabular fracture reconstruction, severe pelvic discontinuity, or cases with inadequate postoperative radiographs were excluded. The sample included patients with primary osteoarthritis, avascular necrosis of the femoral head, femoral neck fracture sequelae, inflammatory arthritis, and other degenerative indications.

All patients underwent standardized preoperative clinical evaluation, anteroposterior pelvis and lateral hip radiographs, and digital templating where feasible. Relevant demographic details, body mass index, primary diagnosis, side of operation, Dorr femoral morphology, presence of acetabular deformity, and clinical suspicion of stiff spine or limited spinopelvic mobility were recorded. THA was performed using a routine institutional protocol with cementless or hybrid implants as indicated by bone quality and surgeon preference. Cup placement was performed by conventional freehand technique assisted by mechanical alignment guides and intraoperative assessment of native acetabular anatomy, transverse acetabular ligament where visible, anterior and posterior walls, and trial stability. The intended target was approximately 40° inclination and 15°–20° anteversion, modified when anatomy, stability, or functional considerations required. Postoperative radiographic assessment was performed using standardized anteroposterior pelvic radiographs with both obturator foramina and teardrops assessed for acceptable positioning. Radiographic inclination was measured as the angle between the inter-teardrop line and the opening plane of the acetabular component. Radiographic anteversion was estimated using the elliptical projection method on anteroposterior radiographs and cross-table lateral assessment when available. For

analysis, target-zone placement was defined as inclination 30°–50° and anteversion 5°–25°. Patients were categorized as within target zone only when both parameters were within range. Clinical outcomes included Harris Hip Score, Forgotten Joint Score-12, limp, impingement symptoms, clinically relevant leg-length discrepancy, instability, and reoperation up to 6 months. Radiographic loosening or migration was assessed on follow-up radiographs.

Data were entered into a structured spreadsheet and analyzed using descriptive and inferential statistics. Continuous variables were expressed as mean ± standard deviation and compared using independent-sample t-test or Mann-Whitney U test depending on distribution.

Categorical variables were expressed as frequency and percentage and compared using chi-square test or Fisher exact test. Effect estimates were reported as mean difference or odds ratio where appropriate. A p value <0.05 was considered statistically significant. The manuscript follows observational study reporting principles and presents de-identified aggregate data only.

Results

A total of 100 primary routine THA patients were analyzed. The mean age was 62.8 ± 9.6 years, 54% were female, and the mean BMI was 25.4 ± 3.8 kg/m². Osteoarthritis was the most common indication, followed by avascular necrosis and fracture sequelae. Seventy-six patients had both cup inclination and anteversion within the predefined target zone. Higher BMI, Dorr type C femoral morphology, and clinically suspected stiff spinopelvic pattern were more frequent among outside-zone cases.

Table 1: Baseline demographic and clinical profile according to acetabular cup target-zone status

Variable	Overall (n=100)	Within target zone (n=76)	Outside target zone (n=24)	p value
Age, years, mean ± SD	62.8 ± 9.6	62.1 ± 9.3	65.0 ± 10.2	0.194
Female sex, n (%)	54 (54.0)	42 (55.3)	12 (50.0)	0.649
BMI, kg/m², mean ± SD	25.4 ± 3.8	24.9 ± 3.6	27.0 ± 4.1	0.018
Primary diagnosis: osteoarthritis, n (%)	48 (48.0)	39 (51.3)	9 (37.5)	0.238
Avascular necrosis, n (%)	28 (28.0)	21 (27.6)	7 (29.2)	0.883
Femoral neck fracture sequelae, n (%)	16 (16.0)	11 (14.5)	5 (20.8)	0.456
Inflammatory/other arthritis, n (%)	8 (8.0)	5 (6.6)	3 (12.5)	0.360
Dorr type C femur, n (%)	19 (19.0)	11 (14.5)	8 (33.3)	0.041
Stiff spine/limited spinopelvic mobility, n (%)	18 (18.0)	9 (11.8)	9 (37.5)	0.004

Mean radiographic inclination was 41.6 ± 6.2° and mean anteversion was 18.9 ± 7.5°. Inclination was within target in 88 patients, anteversion in 83 patients, and both parameters in 76 patients. The most frequent outlier pattern was high anteversion, followed by high inclination. Mean absolute deviation from the planned target was slightly greater for anteversion than inclination.

Table 2: Radiographic acetabular cup-position parameters and target-zone compliance

Radiographic parameter	Mean ± SD / n (%)	Target definition	Within target
Cup inclination, degrees	41.6 ± 6.2	30°–50°	88 (88.0%)
Cup anteversion, degrees	18.9 ± 7.5	5°–25°	83 (83.0%)
Lewinnek safe zone compliance	76 (76.0%)	Inclination 30°–50° and anteversion 5°–25°	76 (76.0%)
Low inclination (<30°)	3 (3.0%)	Below target	—
High inclination (>50°)	9 (9.0%)	Above target	—
Low anteversion (<5°)	7 (7.0%)	Below target	—
High anteversion (>25°)	10 (10.0%)	Above target	—
Absolute deviation from planned inclination	5.1 ± 3.8°	Lower is better	—
Absolute deviation from planned anteversion	6.3 ± 4.9°	Lower is better	—

Clinical recovery was better in patients with target-zone placement. Mean Harris Hip Score and Forgotten Joint Score-12 were significantly higher in the within-zone group. Limp, impingement symptoms, and clinically relevant leg-length discrepancy were more frequent outside the target zone. Instability events were uncommon but numerically higher among outside-zone patients.

Table 3: Early clinical and radiographic outcomes according to cup-position target-zone status

Outcome	Within target (n=76)	Outside target (n=24)	Effect estimate	p value
Harris Hip Score at 6 months, mean ± SD	88.6 ± 7.9	81.2 ± 10.6	Mean difference 7.4	<0.001
Forgotten Joint Score-12, mean ± SD	76.8 ± 12.4	67.1 ± 14.8	Mean difference 9.7	0.002
Limp at 6 months, n (%)	8 (10.5)	8 (33.3)	OR 4.25	0.009
Clinically relevant leg-length discrepancy, n (%)	5 (6.6)	5 (20.8)	OR 3.72	0.047
Impingement symptoms, n (%)	2 (2.6)	4 (16.7)	OR 7.40	0.014
Dislocation/subluxation, n (%)	1 (1.3)	2 (8.3)	OR 6.82	0.089
Reoperation within 6 months, n (%)	0 (0.0)	1 (4.2)	—	0.240
Radiographic loosening/early migration, n (%)	0 (0.0)	1 (4.2)	—	0.240

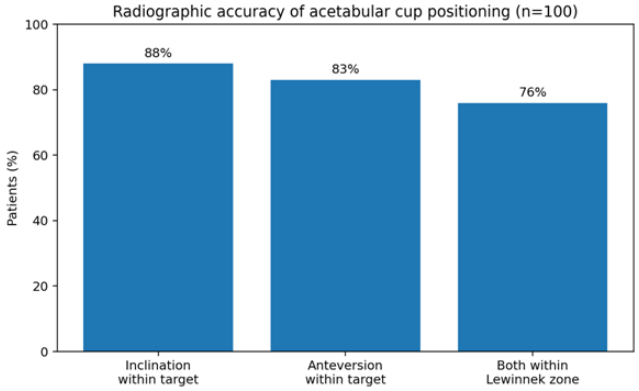


Figure 1: Radiographic accuracy of acetabular cup positioning

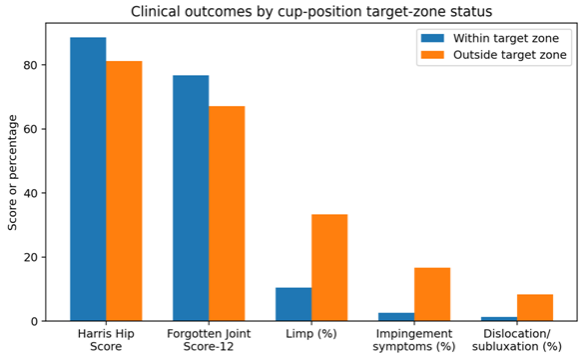


Figure 2: Comparative early clinical outcomes according to target-zone status

Discussion

This prospective study evaluated routine primary THA performed in a tertiary care setting and found that 76% of acetabular cups were placed within a pragmatic radiographic target zone combining inclination and anteversion. Mean inclination of 41.6° and anteversion of 18.9° were close to conventional targets and comparable to values commonly recommended in primary THA practice [1,3]. The 88% inclination compliance and 83% anteversion compliance indicate that conventional freehand/mechanical-guide placement can achieve acceptable accuracy in most routine cases. However, combined target-zone compliance was lower because a patient needed both parameters to be satisfactory, emphasizing that isolated inclination reporting overestimates total acetabular orientation accuracy.

The clinical relevance of these findings is supported by significantly better 6-month Harris Hip Score and Forgotten Joint Score-12 among patients within the target zone. Outside-zone placement was associated with more limp, impingement symptoms, and leg-length discrepancy. These associations are biologically plausible: excessive inclination may increase edge loading and reduce superior coverage, whereas abnormal anteversion may reduce impingement-free flexion or create anterior/posterior instability depending on femoral version and pelvic posture

[2,6]. Although dislocation and reoperation were uncommon, instability was numerically higher outside the target zone. The study was not powered to detect rare instability events, but the direction of effect aligns with the broader literature linking malposition to impingement and dislocation risk [4,5].

Comparison with recent literature shows both agreement and important nuance. Meermans and colleagues emphasized that acetabular orientation and position remain central to short- and long-term THA outcome, but also highlighted that pelvic orientation, approach, and implant design influence the achieved functional position [1]. Seagrave et al. reviewed the evidence on cup position and dislocation and concluded that optimal target values remain debated because measurement methods and definitions vary across studies [4]. Hernández et al. further demonstrated that dislocation can occur even when components lie within the Lewinnek zone and combined anteversion appears acceptable, reinforcing that radiographic safe zones are helpful but insufficient as a stand-alone guarantee of stability [5]. The present study supports this balanced interpretation: conventional target-zone placement was associated with better early outcomes, yet the persistence of outliers and rare instability indicates the need for patient-specific assessment.

Spinopelvic mechanics provide an important explanation for why universal safe zones may fail. Degenerative lumbar stiffness reduces posterior pelvic tilt during sitting, functionally decreasing acetabular anteversion and increasing posterior impingement/anterior dislocation risk; conversely, excessive pelvic rollback may functionally over-antevert the cup [7,8]. In the present cohort, clinically suspected stiff spine or limited spinopelvic mobility was significantly more common in the outside-zone group. This may reflect technical difficulty due to deformity and contracture, but it also suggests that such patients require greater preoperative attention. Contemporary approaches recommend standing and sitting lateral radiographs for high-risk patients, assessment of pelvic incidence-lumbar lordosis mismatch, and individualized cup targets rather than routine application of a single safe zone [8-10]. Pang et al. reported that patient-specific safe-zone planning can improve positioning accuracy relative to stable reference targets, and recent personalized safe-zone studies similarly support a more nuanced approach in patients with spinopelvic pathology [10,11].

From a practical standpoint, the findings have implications for centres where navigation or robotic systems are not universally available. First, every primary THA program should maintain a radiographic audit of cup inclination, anteversion, outlier pattern, and complications. Second, intraoperative pelvic position must be actively controlled because lateral tilt, flexion, and rotation can distort apparent guide orientation. Third, high-risk patients—obesity, stiff spine, Dorr type C femur, dysplasia spectrum, protrusio, post-traumatic anatomy, or severe contracture—should undergo more detailed preoperative planning and may benefit from fluoroscopy, navigation, robotics, CT planning, or senior-surgeon supervision. Robotic and navigation studies report improved precision in achieving planned cup orientation, but cost, availability, learning curve, and case selection remain relevant, particularly in public-sector and resource-limited contexts [9,12].

The study has limitations. It was single-centre and observational, and radiographic anteversion from plain films is less precise than CT-based measurement. Follow-up was limited to 6 months, so wear, late loosening, and late revision could not be evaluated. Spinopelvic mobility was clinically identified rather than uniformly quantified by standing/sitting lateral radiographs in every patient.

Finally, the study used a conventional target-zone definition to permit practical audit, although true ideal placement may differ by patient. Nevertheless, the study offers clinically relevant prospective data from routine primary THA and demonstrates that even a simple radiographic audit can identify technical outliers and outcome gradients. Future work should integrate CT validation, formal spinopelvic classification, combined anteversion analysis, and longer-term implant survivorship.

Conclusion

In this prospective study of 100 routine primary THA patients, 76% of acetabular cups were positioned within a conventional combined radiographic target zone. Target-zone placement was associated with better early functional scores and fewer impingement-related symptoms. Conventional safe-zone assessment remains useful for audit and quality improvement, but it should be complemented by meticulous pelvic positioning, preoperative templating, combined anteversion awareness, and selective spinopelvic or patient-specific planning in high-risk cases.

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