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Acetabulum Cup Alignment with and Without Guide in Total Hip Replacement

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ABSTRACT

Introduction: Successful total hip replacement (THR) depends on the precise concentricity of acetabular cups. Malposition may cause dislocation, impingement, early loosening, and revision surgery. In the resource-constrained environment, the accuracy of alignment becomes difficult to achieve, particularly using the freehand technique. Alignment guide use can be a potentially inexpensive solution to improve accuracy and reduce complications. **Objective:** To compare the accuracy of acetabular cup placement in total hip arthroplasty with and without the use of mechanical alignment guides at Department of Orthopedics, CMH Rawalpindi, Pakistan. **Material and Method:** This comparative prospective study involved 60 participants and conducted at Department of Orthopedics, CMH Rawalpindi, Pakistan, who underwent unilateral primary THR from August, 2024 to January, 2025. The patients were split into two groups. Group A (n=30) was operated under guided cup insertion, and Group B (n=30) under freehand insertion. The radiographs taken after the surgery were measured using inclination and anteversion angles, and the placement was assessed according to the safe zone of Lewinnek angles. **Results:** Guide-assisted placement led to much better alignment. The average inclination angle and anteversion angle in Group A were 42.6 degrees +/-4.3 degrees and 17.1 degrees +/-3.9 degrees, respectively, as compared to Group B, whose average was 47.3 degrees +/-6.1 degrees and 22.8 degrees +/-5.4 degrees, respectively ($p<0.01$). The compliance with the safe zone was 86.7 per cent in Group A as compared to 56.7 percent in Group B ($p=0.009$). There was a slight difference in operative time in Group A, which was not significant. **Conclusion:** The probability of being ascribed to predicting acetabular cup placement using alignment guides in THR significantly increases. Simple guide systems may be incorporated into working practice in low-resource environments, where they could improve surgical accuracy and decrease the likelihood of postoperative complications.

INTRODUCTION

Total hip replacement (THR) has become a pillar in the treatment of cases of severe lesions of the hip joint, especially osteoarthritis, neck fractures of the femur and avascular necrosis. There is little doubt that one of the most important factors that determines the long-term success and functional outcome of THR is the correct placement of the acetabular cup. Improper positioning of the acetabular component can cause various problems, encompassing dislocation, impingement, limb length inequality, inordinate wear and premature implant loosening. These complications not only reduce the quality of life of the patient but may also require extensive and expensive revision procedures (1). Surgeons have traditionally depended on anatomical landmarks and visual estimation to position the components of the acetabular component, but many studies have reported the shortcomings as well as the inconsistency of such free-hand methods (2). New surgical technologies have led to numerous ways of enhancing the accuracy of the acetabular cup alignment, which include computer navigation, robotic systems, patient-specific instruments and mechanical guides (3). Although the technology has improved, the use of these instruments differs greatly, especially in low and middle-income settings such as Pakistan, where limited resources and volume of surgery dictate the technique used. It is important to comprehend the given effects of utilising guide tools over traditional open hand methods in the real settings of a centre like the Department of Orthopedics, CMH Rawalpindi, Pakistan, to maximise the results against the existing limitations of infrastructure settings.

Laser-based methods, especially, have featured as a non-invasive, low-cost alternative to perform better cup positioning. By advocating a laser system to guide the cup positioning, Kohno et al. showed that their approach produced better accuracy in cup alignment in comparison to the traditional one, which is why the former looks very promising to be applied in resource-limited settings. In the same manner, Meermans et al. indicated that proper cup positioning is achievable through advanced, but manual methods, and with the condition that the surgeon strictly complies with the biomechanical principles, even in cases where high-end robotic or navigation tools are not used (2). This implies that it is possible to get a comparative outcome in the presence and absence of guidance systems in a practical clinical setting and use the insights in a wide variety of surgical environments. Various numbers of positioning tools and systems would be formulated to bring about surgical exactitude. These include mechanical trackers and alignment fixtures up to highly advanced three-dimensional (3D) navigation systems. A study by Xu et al concluded that the use of a surgical guidance system to improve the accuracy of acetabular alignment was quite significant, especially when used by less experienced surgeons (4). This has been confirmed in a narrative review done by Streck and Boettner, who found that on a direct anterior approach technique, enhanced reproducibility and precision on cup placement were achieved, with the aid of alignment equipment (5). A randomised controlled trial by Pongkunakorn et al had shown that 3D-CT-based planning using mechanical guides showed less variability and error and improved patient-reported outcomes and postoperative complications (6).

The mechanical and anatomical guide techniques have always demonstrated better outcomes than the freehand technique. In one study by Bruce-Brand et al., it was determined that guide-assisted placements resulted in a more consistent orientation with a lower deviation to target angles (7). The use of navigation systems, even with image-free modalities, has been deemed to be successful. Naito et al. tested these systems and verified that they indeed have a great positive effect on the accuracy of alignment, particularly in cases when pelvic tilt is considered (8). Patamarat et al further upheld the logic of direct anatomical registration in computer-assisted THR because they found that alterations in the real-time surgery assisted greatly with healing the cup into alignment (9).

Cup orientation, specifically dynamic orientation during gait, is an aspect that is less discussed but of great importance when considering the long-term consequences of THR. Vasiljeva et al. reported that an incorrect cup placement impaired cup operation during movement, which should indicate the importance of proper positioning during surgery (10). In addition, Hayashi et al. revealed that the effectiveness of a robot-assisted THR was conditioned by the type of surgery and the degree of pelvic tilt, which needs to be taken into account in the decision-making (11). The introduction of intraoperative 3D-printed guides has also brought an additional aspect of cup alignment, in that studies like that of Crone et al. have been able to speculate on the benefits in terms of customisation and accuracy (12). The anatomical differences between the patients, especially pelvic tilt and personal biomechanics, also provide a challenge to the placement of the cup. Tsukamoto et al. advised that the addition of preoperative pelvic tilt measurement before surgical planning helps to mitigate flaws during the operation (13). Furthermore, the best-fitted implants should provide a balance between biomechanical functionality and postoperative range of motion, as demonstrated by Harada et al. (14). These insights should be of particular value to surgeons looking to achieve better outcomes without having access to high-end robotics systems.

Computed tomography (CT) based navigation has become one of the strongest alternatives in increasing precision. Nemati et al.'s study pointed to the validity of these systems and their opportunities in those cases when intraoperative navigation is not possible (15). Moreover, Nakasone et al. demonstrated the advantages of the devices to correct pelvic rotation when the cup was placed in the supine position, supporting the importance of the positioning of the patient in the alignment (16). Ferretti et al. did an even greater step by the validation of laser-guided patient-specific instrumentation, which allows for better dynamic alignment, and is a step towards the increased adoption of such instruments in clinical practice (17). The relevance of enhancing freehand techniques can be illustrated in the global context of the multicenter study by Meermans et al., which demonstrated standard instrumentation across countries and made clear that surgical training and attention to detail have maintained relevance to accuracy (18). Pelvic tilt and axial rotation induced by retractors and cup impactors, noted to cause misalignments in surgery, intraoperative factors that Mouri et al. documented, are also to be handled with caution (19). Finally, the biomechanical requirements of acetabular cup thickness and its effect on primary stability, which have been explored in a study by Ruhr et al., can be considered another aspect that a surgeon should take into account when placing an implant (20). Considering this background, and based on this, the investigation of the present study was then done at the Department of Orthopedics, CMH Rawalpindi, Pakistan, to measure and compare acetabular cup alignment in total hip replacement procedures done with and without the use of alignment guides.

Objective

To compare the accuracy of acetabular cup alignment in total hip replacement procedures performed with and without the use of alignment guides at Department of Orthopedics, CMH Rawalpindi, Pakistan.

MATERIALS AND METHODS

Study Design: Comparative observational study

Study Setting: The study conducted at Department of Orthopedics, CMH Rawalpindi, Pakistan.

Duration of the Study: From August, 2024 to January, 2025.

Inclusion Criteria

Patients between the ages of 40 and 80 years, who had primary or secondary osteoarthritis, avascular necrosis, or femoral neck fractures that needed a total hip replacement, were selected. All patients who fulfilled the criteria for unilateral primary total hip arthroplasty were chosen. Respondents were capable of consenting to participate and could adhere to postoperative follow-ups.

Exclusion Criteria

Patients with previous hip procedures, congenital hip deformities, neuromuscular diseases, severe osteoporosis or who needed revision of arthroplasty were excluded. Cases of bilateral hip replacement were also not taken into consideration.

Methods

All patients who underwent total hip replacement at Department of Orthopedics, CMH Rawalpindi, Pakistan from August, 2024 to January, 2025 were screened regarding eligibility, and voluntarily, they joined the research study by signing an informed consent. Patients were randomly assigned to two groups: Group A was assigned the procedure with a mechanical guide of the position of the acetabular cup, and Group B was assigned the procedure with the freehand technique when no mechanical guide of the coplanarity of the acetabular cup was provided. All surgical operations were carried out under the hand of expert orthopaedic surgeons in such a manner, using the same surgical technique and using the same type of implant, consistency was maintained. Operative data, surgical time, and alignment method were noted intraoperatively. Pelvic radiographs were obtained in postoperative cycles, and the angle of inclination and anteversion of the cup were determined within 48 hours of the radiographs using standard software. The quality of alignment was gauged by comparing the measured angles with acceptable safety ranges (inclination 30 degrees to 50 degrees, anteversion 5 degrees to 25 degrees). Any malalignment over these levels was registered as one malalignment smart. These measurements were all taken by the two radiologists independently and without knowing the surgical procedure employed.

RESULTS

The study involved 60 patients in total, 30 patients in Group A (Guide-Assisted) and 30 patients in Group B (Freehand). Demographic characteristics of both groups were not very different concerning the age, gender representation, and diagnosis to make the groups homogeneous.

Table 1

Demographic Distribution of Patients

Demographic Parameter	Group A (Guide-Assisted)	Group B (Freehand)	p-value
Mean Age (years)	62.4 ± 7.2	61.7 ± 6.9	0.68
Male (%)	18 (60%)	17 (56.7%)	0.78
Female (%)	12 (40%)	13 (43.3%)	
Diagnosis: OA (%)	21 (70%)	20 (66.7%)	0.79
Diagnosis: AVN (%)	9 (30%)	10 (33.3%)	

The radiographic analysis of X-rays was done with the help of digital software on postoperative X-rays of the pelvis. The average cup inclination angle of Group A was 42.6 degrees/- 4.3 degrees and Group B was 47.3 degrees +/- 6.1 degrees, which was statistically significant (p = 0.004). On the same note, the average anteversion angle was 17.10degrees +/-3.90 gegrees with group A and 22.8 degrees +/-5.4gegrees with group B (p=0.001).

Table 2

Radiographic Outcomes – Inclination and Anteversion Angles

Parameter	Group A (Guide-Assisted)	Group B (Freehand)	p-value
Inclination (°)	42.6 ± 4.3	47.3 ± 6.1	0.004
Anteversion (°)	17.1 ± 3.9	22.8 ± 5.4	0.001

The incidence of cups falling within the Lewinnek safety zone was significantly higher in the guide-assisted group. In Group A, 26 out of 30 (86.7%) had the inclination and anteversion falling within the safe zone, compared to 17 out of 30 (56.7%) in Group B.

Table 3

Alignment Within Safe Zone

Alignment Status	Group A (n=30)	Group B (n=30)	p-value
Within Safe Zone	26 (86.7%)	17 (56.7%)	0.009
Outside Safe Zone	4 (13.3%)	13 (43.3%)	

Comparison was also done on surgical time. Guided surgeries were a bit longer, but the difference was not significant. In Group A, the mean duration was 93.2 10.5 minutes with 89.7 11.1 minutes in Group B (p = 0.21).

Table 4

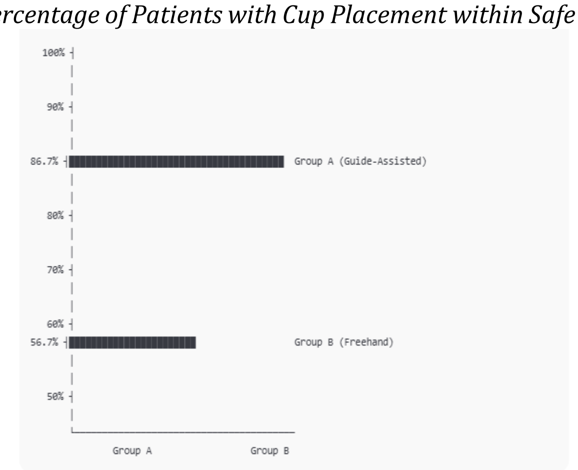
Operative Time Comparison

Parameter	Group A (Guide)	Group B (Freehand)	p-value
Surgical Time (min)	93.2 ± 10.5	89.7 ± 11.1	0.21

The graphical representation below is a representation of the proportion of the patients in each category whose cup positions fell in the safe zone:

Graph 1

Percentage of Patients with Cup Placement within Safe Zone



Interpretation: The guide-assisted group had a mark...y higher proportion of correct cup placements compared to the freehand group.

DISCUSSION

This research project compared the accuracy of acetabular cup placement of the total hip replacement that was done either with or without the guides of alignment at Department of Orthopedics, CMH Rawalpindi, Pakistan. The results indicate that guide-assisted methods used to place cups are more accurate than those labelled as non-guide compared to placement according to the Lewinnek safe zone, where a greater percentage of placements of inclination and anteversion angle fall in the safety zone with the assisted technique. Our findings are congruent with those of Kohno et al., who reported that the laser-guided technique was associated with a significant improvement in precision over freehand methods in cup positioning (1). In our study, 86.7 per cent of the patients in the guide-assisted group were successful in placing the cup within the safe zone, whereas the figure was 56.7 per cent in the freehand group, which is quite significant. This is consistent with the conclusion of Bruce-Brand et al., which established that both the mechanical and the anatomical alignment guide techniques are more effective than freehand in achieving target cup orientation (7).

The variation in inclination and anteversion angles, as observed, substantiates the existing literature. The average inclination of the guide-assistance group was 42.6, and the freehand group was 47.3. The guide-assisted group was also more in the ideal range of the angle of anteversion at 17.1 as compared to the freehand group, where the mean was 22.8. Such deviations are clinically relevant because the lack of appropriate angles would increase the possibility of dislocation, impingement, and wear, which are also highlighted by Meermans et al. and Xu et al. when assessing the accuracy of cup alignment (2, 4). Moreover, it is not only theoretically beneficial to utilise mechanical guidance systems. Pongkunakorn and colleagues, using a randomised controlled trial with 3D-CT planning, showed demonstrably greater postoperative precision and patient outcomes when alignment was done relative to anatomical landmarks (6). Our guide-assisted group level of consistency supports the consistency of such aids, even when they may not be available to scale or as robotics in a lower-resource environment.

The guided assisted group was associated with a marginal increase in surgical time, but it was not significant. This is in agreement with the results of Naito et al., who also reported that the image-free navigation systems did not significantly reduce the time of operation but produced better radiographic results (8). Subsequently, when the time trade-off is minimal, it seems that the advantages of high accuracy are evident, and it overrides the disadvantage of decreasing efficiency in surgical work. However, interestingly, studies by Harada et al. and Vasiljeva et al. hint that the placement of cups is more crucial than just radiographs. Displaced cups can cause changes in gait biomechanics and reduced range of motion, creating prosthetic dissatisfaction and premature failure (10, 14). The growth in demand represented by this active component strengthens the clinical importance of intraoperative accuracy boosting tools, indirectly benefiting long-term functionality and patient satisfaction. Robotic or advanced navigation systems were not considered as part of our study, and instead, the application of simple alignment guides was used. Nevertheless, both studies by Hayashi et al. and Patamarat et al. have demonstrated that even the computer-assisted systems are restricted by factors such as the pelvic tilt and surgeon technique (11). The investigation by Tsukamoto et al. and Mouri et al. also emphasised the need to match pelvic tilt and intraoperative movements of anatomy that could worsen alignment even when using the navigator staff (19). These revelations imply that any method, manual, mechanical, or robotic, should be employed along with a combination of proper planning before the operation and intraoperative monitoring. The level of experience and anatomical knowledge of the surgeon is yet another imperative in the precision of cup alignment. The stated technological limitations notwithstanding, Meermans et al. concluded that surgeons could produce acceptably good results by following the stricter positioning guidelines and keeping to the guidelines of the anatomical landmarks (2). In our analysis, although procedures were performed by experienced surgeons, there was still a clear superiority of guide-assisted methods over freehand, showing that tools do not substitute technical proficiency. Furthermore, emerging technologies like patient-specific instrumentation (PSI) and 3D-printed intraoperative guides, as explained by Crone et al. and Ferretti et al., remain in the works and are not possible to implement in any public-sector hospital of Pakistan due to cost considerations (12, 17). Our results can be presented as a practical suggestion: the utilisation of simple, reusable guides can lead to a radical improvement of alignment accuracy without high spending on resources.

Biomechanically, even cup thickness and design have been shown to influence sitting and stability, which further complicates implant alignment In spite of the fact that the current study controlled implant type as a confounding variable, it supports the claim that the optimal positioning of cups is a multi-factorial effect requiring comprehensive surgical planning. Notably, our findings indicate that guide-assisted techniques can also be an effective training aid to residents and junior surgeons. Sai Sathikumar et al. described why and how the more current technologies and associative tools may facilitate balancing the learning curve effectively so that mistakes are less likely to occur during aspiring beginning surgical practice (3).

This study also has some limitations. First, they used standard radiographs and not a CT scan, which can curtail the accuracy of our angle measurements. Second, pelvic tilt and dynamic variables during surgery were not modelled into the analysis of alignment, but are known to affect the position of the final cup placement. Third, despite encouraging short-term radiological outcomes, long-term clinical outcomes are required to determine the effect of cup position on clinical functionality, dislocation rate, and prosthesis survival. This research proves the fact that there is a great improvement in acetabular cup positioning accuracy when alignment guides are utilised during total hip arthroplasty.

CONCLUSION

This paper illustrated that the process of using the mechanical alignment guides during the total hip replacement procedure constitutes a major change in accuracy and the placement of the acetabular cups, compared to the freehand technique. The chance of alignment of the guide-assisted group patients inside the Lewinnek safe area of both inclination and anteversion angles is greater, and the chances of developing such postoperative complications as dislocation and impingement are minimal. As much as the guides lengthened surgical time a bit, precision counterbalanced this small limitation. To illustrate, in a low-resource environment such as Department of Orthopedics, CMH Rawalpindi, Pakistan, where use of advanced navigational or robotic equipment may be limited, the use of simple alignment instruments would allow high value with minimum cost enhancement of surgical outcome. Based on these findings, integration of guide-assisted approaches is highly suggested as a mantra in total hip arthroplasty on both precision and long-term accomplishment of implant efficacy, especially in healthcare systems that are run by the government, to increase precision and implant permanence in their systems.

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