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Research Article

Lower Extremity Alignment Changes Following Total Hip Arthroplasty in Patients with Traumatic and Non-Traumatic Degenerative Hip Disease: A Registry-Based Study

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Abstract

Introduction: Total hip arthroplasty (THA) is widely performed for various hip disorders, including post‑traumatic conditions. However, its effect on coronal lower limb alignment remains debated, and data on early postoperative alignment changes are limited. This registry‑based study aimed to evaluate changes in lower extremity alignment following THA in patients with traumatic and other hip disorders.

Method: A consecutive series of 40 patients (40 hips) who underwent primary THA between March 2025 and March 2026 was included. Bilateral standing full‑leg radiographs were obtained preoperatively and two months postoperatively. Radiographic parameters measured included lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), hip‑knee‑ankle angle (HKA), joint line convergence angle (JLCA), and mechanical femorotibial angle (mFTA).

Result: The cohort comprised 23 males and 17 females, with a mean age of 63 ± 12 years. On the operated side, no significant changes were observed for LDFA (89.9° ± 3.4° to 89.3° ± 3.5°, p = 0.203), MPTA (86.7° ± 3.0° to 87.0° ± 3.1°, p = 0.008), HKA (3.2° ± 5.2° to 2.4° ± 5.0°, p = 0.121), JLCA (1.8° ± 2.3° to 2.2° ± 2.8°, p = 0.222), or mFTA (5.1° ± 5.8° to 4.5° ± 5.7°, p = 0.788). On the contralateral side, none of the parameters changed significantly (all p > 0.05). Subgroup analysis by trauma history showed small but statistically significant differences in LDFA (p = 0.034) and MPTA (p = 0.010) changes on the operated side, though overall limb alignment parameters remained stable.

Conclusion : At two months after THA, coronal lower limb alignment remained stable on both the operated and contralateral sides in this predominantly non-traumatic cohort. These radiographic findings indicate that THA does not induce clinically meaningful early alterations in coronal lower limb alignment, as measured on standing full-leg radiographs. However, this study did not assess clinical outcomes such as pain, function, gait, or patient-reported outcomes, and no conclusions can be drawn regarding the clinical significance of the observed alignment stability or the need for routine early follow-up. Furthermore, the findings are limited to the early postoperative period; longer follow‑up is essential to assess potential late changes and their clinical implications.

Keywords: Total hip arthroplasty; lower limb alignment; coronal plane; trauma; registry study; hip knee ankle angle.

Introduction

Total hip arthroplasty (THA) is one of the most common surgical procedures in orthopedics, offering significant improvements in function and quality of life for patients with osteoarthritis (OA) [1,2]. It aims to reconstruct the anatomical alignment of the hip joint compromised by osteoarthritis (OA) or osteonecrosis of the femoral head (ONFH) [3]. In addition to degenerative and vascular etiologies, trauma remains a major indication for THA, with displaced femoral neck fractures and post-traumatic osteoarthritis accounting for a substantial

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proportion of procedures worldwide. Trauma increases Degenerative joint disease of the hip [4]. Post-traumatic deformities such as malunion, limb-length discrepancy, and altered femoral offset disrupt the biomechanical balance of the hip joint, leading to abnormal loading of the lower extremity and potentially accelerating the development of knee osteoarthritis .

THA not only influences hip alignment but also affects leg and patellar alignment on both the ipsilateral and contralateral sides [5-8]. Changes in knee alignment after THA may worsen postoperative outcomes and increase the risk of knee OA progression [9-10].

Proper lower limb alignment (LLA) is crucial for maintaining joint biomechanics and ensuring even load distribution across the lower extremity. Even small deviations can influence joint kinematics and may accelerate the onset or progression of OA, particularly in the knee joint [11]. Unlike TKA, THA is not an operation that is commonly known to control lower limb alignment. However, we can reasonably expect that lower limb alignment is influenced by changes in the hip joint profile after THA, which can eventually affect knee joint condition [12].

Following THA, alignment changes commonly include a varus alignment in the ipsilateral leg and a valgus alignment in the contralateral leg [13, 14]. Lower limb alignment may be affected in patients with hip OA and leg length discrepancy for an extended period [15]. A study showed that patients with unilateral hip OA have a higher incidence of lateral knee OA than medial knee OA on the ipsilateral side [16].

Some studies have evaluated the effects of THA on the knee joint [6, 17-19]. Ollivier et al. [6] and van Drongelen et al. [19] reported that the hip–knee–ankle angle (HKA) changes in the varus direction after THA. In particular, van Drongelen et al. showed that this change could cause progression of medial knee OA [19]. In contrast, Umeda et al. reported that the ipsilateral knee joint changed in the valgus direction after THA, and this change was associated with a decreased femoral offset (FO) [17]. These findings are supported by other authors who also describe changes in the HKA in the varus direction following THA [1, 14, 20]. Van Drongelen et al. also found that THA alters overall LLA and even postulated that a more varus HKA after THA could cause progression of medial knee osteoarthritis [19]. Ollivier et al. also reported changes in the HKA angle [6]. However, these alterations were minor and did not significantly affect the biomechanical parameters of the ipsilateral knee joint. Because of these inconsistent findings, the impact of THA on overall LLA, and the potential for these alterations to contribute to the progression of knee osteoarthritis, remain unclear [1, 6].

Previous studies have identified several parameters that may contribute to changes in postoperative leg alignment. Factors such as medial shift of the hip center, increased femoral offset, and leg lengthening have been associated with varus changes in the ipsilateral leg, indicated by an increased hip-knee-ankle angle (HKAa) [13, 14]. However, the decisive factors determining postoperative leg alignment remain unclear because studies report variability across factors. Moreover, the parameters influencing contralateral leg-alignment changes have not been identified. This uncertainty may stem from unidentified factors or the multifactorial nature of parameters associated with postoperative alignment [3].

This study aimed to assess the effect of THA on coronal limb alignment in patients with various hip disorders, using a registry-based analysis. Specifically, we evaluated pre- to postoperative changes in lower extremity alignment parameters (LDFA, MPTA, HKA, JLCA, mFTA) on both the operated and contralateral sides at two months following primary THA. We compared our findings with the existing literature.

Methods

This registry-based data analysis includes a consecutive series of 40 hips from 40 patients who underwent primary THA with hip prosthesis implantation between March 2025 and March 2026. Ethical approval by the local institutional board was obtained before the study (IR.BMSU.REC.1404.191).

Patients of all sexes aged more than 18 years, and meeting the surgical indication for primary total hip arthroplasty (because of hip osteoarthritis, avascular necrosis of the hip, trauma, and Developmental Dysplasia of the Hip (DDH)) were included in this study. Among the patients, one (3%) patient had a major trauma, and 13 (32%) reported minor trauma, most of which were ground-level falls.

We excluded patients with pregnancy, pelvic septic arthritis, bacteremia or active infection, severe peripheral vascular disorders, missing hospital data, missing standard radiographs, or prior ipsilateral total knee arthroplasty (TKA). After excluding 20 hips that did not meet the inclusion criteria, the study cohort comprised 40 hips.

Patients were required to have undergone pre- and postoperative lower limb X-rays. Before and two months after surgery, Bilateral standing radiographs of the entire leg, including the hip, knee, and ankle joints, were taken at a single radiology center using the same protocol, with the lower limbs in controlled rotation. An orthopedic surgeon performed measurements on each anonymized radiograph manually, independently, at 1-month intervals.

Angles were defined and measured as follows (see Figure 1):

Lateral Distal Femoral Angle (LDFA): The angle between the anatomical axis of the femur and the femoral joint line of the knee.

Medial Proximal Tibial Angle (MPTA): The angle between the anatomical axis of the tibia and the line tangent to the tibial plateau.

Joint Line Convergence Angle (JLCA): The angle between the tibial and femoral joint lines of the knee.

Mechanical Femoral–Tibial Angle (MFTA): The angle between the mechanical axis of the femur and the mechanical axis of the tibia. The adjusted hip–knee–ankle angle (aHKA) was then calculated as MPTA - LDFA.

We analyzed all radiographic parameters—including lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), hip-knee-ankle angle (HKA), joint line convergence angle (JLCA), and mechanical femorotibial angle (mFTA)—as continuous variables. Data are presented as mean ± standard deviation (SD) or median, as appropriate. Variables were assessed for normality using the Shapiro–Wilk test. Preoperative and postoperative measurements within the same limb (operated side and contralateral side separately) were compared using the paired t-test for normally distributed variables or the Wilcoxon signed-rank test for non-normally distributed variables. A p-value < 0.05 was considered statistically significant. For subgroup comparisons between trauma and non-trauma groups, the Mann-Whitney U test was employed.

This study represents a consecutive series of all patients who underwent primary total hip arthroplasty at a single institution over one year (March 2025 to March 2026) and met the inclusion criteria, as derived from an institutional total hip arthroplasty registry. A formal a priori sample size calculation was not performed, as the primary objective was to describe early alignment changes in a real-world clinical cohort using available registry data rather than to test a specific hypothesis with predetermined effect sizes. Nevertheless, a post-hoc power analysis was conducted to contextualize the study's ability to detect meaningful changes. Based on previously reported standard deviations for HKA angle changes following THA in similar populations (approximately 5–6°) [1, 6, 14, 19], and assuming a clinically meaningful difference of 2.0°—the minimum change in coronal alignment associated with altered knee joint loading and progression of knee osteoarthritis based on biomechanical studies [10, 16]—a two-tailed paired t-test with $\alpha = 0.05$ and a sample size of 40 patients provides approximately 80% power ($\beta = 0.20$) to detect such a difference. Using the actual observed standard deviation of HKA change in this cohort (2.93°), the study provides 80% power to detect a mean HKA change of approximately 1.4°, which is below the 2.0° threshold considered clinically meaningful. However, the study is substantially underpowered for subgroup analyses, particularly comparisons between traumatic and non-traumatic etiologies, which would require larger sample sizes to detect between-group differences. These subgroup analyses should be considered exploratory and hypothesis-generating. The sample size of 40 patients is comparable to or exceeds that of several similar published studies examining alignment changes after THA [1, 6, 19, 22]. Furthermore, as a registry-based study, we determined the sample size based on the availability of complete pre- and postoperative radiographic data during the study period, reflecting the pragmatic nature of registry research. The discussion explicitly addresses the limitations of this sample size, particularly for subgroup analyses and detecting small effect sizes.

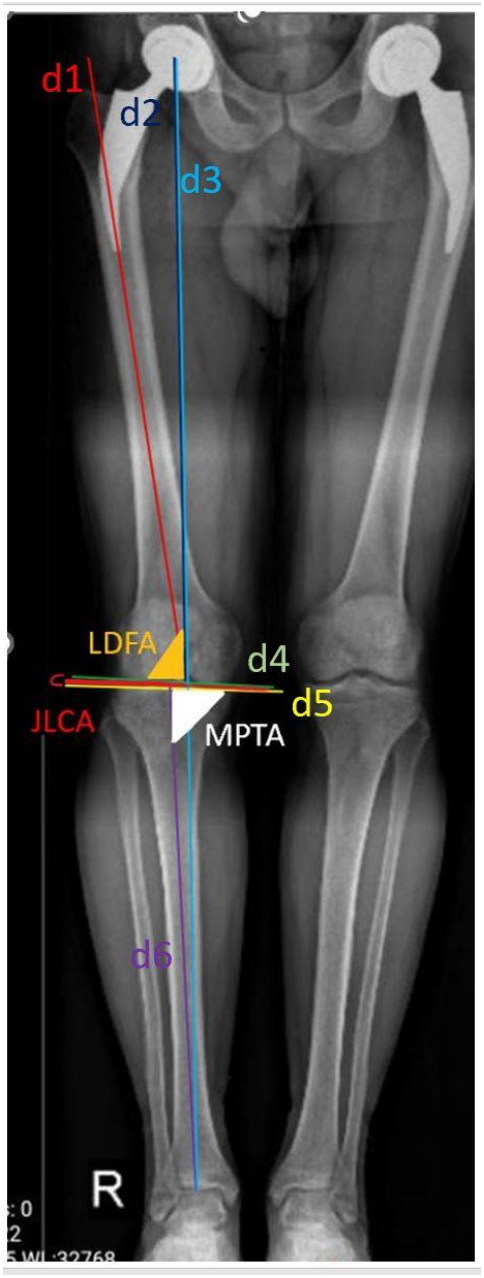


Figure 1: definition of angles including LDFA, MPTA, JLCA, mFTA. d1: Anatomical axis of the femur, d2: Mechanical axis of the femur, d3: Mechanical axis of the limb, d4: Line parallel to the articular surface of the distal femur, d5: Line parallel to the articular surface of the proximal tibia, d6: Anatomical and mechanical axis of the tibia. MFTA: Angle between d3 and the vertical axis, LDFA: Angle between d1 and d4, JLCA: Angle between d4 and d5, MPTA: Angle between d6 and d5.

Results

A total of 40 patients who underwent total hip arthroplasty were included. The cohort consisted of 23 males (57%) and 17 females (43%), with a mean age of 63 ± 12 years and a mean body mass index of 26.8 ± 3.5 kg/m².

Pre- and postoperative alignment measurements for the operated limb and the contralateral limb are detailed in Table 1.

On the operated side, the mean lateral distal femoral angle (LDFA) was 89.9° ± 3.4° preoperatively and 89.3° ± 3.5° postoperatively (P = 0.203). The medial

proximal tibial angle (MPTA) changed from 86.7° ± 3.0° to 87.0° ± 3.1° (P = 0.008); The joint line convergence angle (JLCA) changed from 1.8° ± 2.3° to 2.2° ± 2.8° (P = 0.222), and the mechanical femorotibial angle (mFTA) decreased from 5.1° ± 5.8° to 4.5° ± 5.7° (P = 0.788), neither of which reached statistical significance.

On the contralateral (non‑operated) side, none of the alignment parameters changed significantly between the preoperative and postoperative assessments (all P > 0.05). The LDFA was 89.7° ± 2.8° (median 90.0°) preoperatively and 89.6° ± 2.8° (median 90.0°) postoperatively (P = 0.673). The MPTA was 85.7° ± 5.5° (median 86.1°) and 86.1° ± 3.5° (median 86.0°), respectively (P = 0.471). The JLCA changed from 2.0° ± 2.3° (median 1.7°) to 2.3° ± 2.5° (median 2.3°) (P = 0.192), and the mFTA from 5.9° ± 5.4° (median 5.5°) to 6.2° ± 5.3° (median 5.2°) (P = 0.394).

In summary, total hip arthroplasty did not meaningfully alter coronal plane alignment of the lower extremity, either on the operated or contralateral side.

Among the 40 patients, 13 (32.5%) reported a history of minor trauma, predominantly ground-level falls, while 27 (67.5%) had no such history. The distribution of underlying diagnoses differed between the two groups, with all patients who reported minor trauma having degenerative joint disease (DJD) as their primary diagnosis (100.0%), compared to 66.7% in the non-trauma group. The remaining diagnoses in the non-trauma group included avascular necrosis (AVN) in 22.2%, developmental dysplasia of the hip (DDH) in 3.7%, Perthes disease in 3.7%, and traumatic etiology in 3.7%. However, this difference in diagnostic distribution was not statistically significant (Fisher's Exact Test, p = 0.190), likely because of the small sample size and the fact that 80.0% of cells had expected counts less than 5.

Demographic characteristics were comparable between patients with and without minor trauma. The mean age was 63.62 ± 8.70 years in the trauma group versus 62.19 ± 13.50 years in the non-trauma group (Mann-Whitney U test, p = 0.806). Body mass index (BMI) was slightly lower in the trauma group (26.07 ± 3.41 kg/m²) compared to the non-trauma group (27.15 ± 3.55 kg/m²), though this difference was not statistically significant (p = 0.348). Gender distribution was also similar between groups, with males comprising 53.8% of the trauma group and 59.3% of the non-trauma group (p = 1.000, Fisher's Exact Test).

Subgroup Analysis of Alignment Changes by Trauma Status

When comparing alignment changes between patients with and without minor trauma, some differences emerged (Table 2). On the operated side, patients without trauma showed a mean decrease in LDFA of -1.14° ± 3.07°, whereas those with trauma demonstrated a mean increase of +0.54° ± 2.16° (p = 0.034). Similarly, MPTA changed significantly between groups: the non-trauma group showed a minimal increase of +0.10° ± 0.46°, while the trauma group showed a larger increase of +0.47° ± 0.44° (p = 0.010). These differences suggest that patients with a history of minor trauma may experience slightly different early alignment responses following THA, particularly at the femoral and tibial levels.

In contrast, changes in HKA (p = 0.161), JLCA (p = 0.149), and mFTA (p = 0.573) on the operated side did not differ significantly between trauma and non-trauma groups. On the contralateral, non-operated side, none of the alignment parameter changes differed significantly between the two groups (all p > 0.05), indicating that minor trauma did not affect alignment changes on the opposite limb.

Table 1 : Pre- and Postoperative Lower Limb Alignment Changes in Ipsilateral and Contralateral Limbs Following Total Hip Arthroplasty. (Values are reported as mean ± standard deviation; median is shown in parentheses.)

Items	Pre-operative	Post-operative	P-value
Ipsilateral limb			
Lateral Distal Femoral Angle	89.9 ± 3.4 (89.3)	89.3 ± 3.5 (89.6)	0.203
Medial Proximal Tibial Angle	86.7 ± 3.0 (87.1)	87.0 ± 3.1 (87.0)	0.008
hip-knee-ankle angle	-3.2 ± 5.2 (-1.7)	-2.4 ± 5.0 (-1.9)	0.121
Joint Line Convergence Angle	1.8 ± 2.3 (1.7)	2.2 ± 2.8 (1.9)	0.222
Mechanical Femorotibial Angle	5.1 ± 5.8 (4.0)	4.5 ± 5.7 (3.5)	0.788
Contralateral limb			
Lateral Distal Femoral Angle	89.7 ± 2.8 (90.0)	89.6 ± 2.8 (90.0)	0.673
Medial Proximal Tibial Angle	86.0 ± 4.2 (86.1)	86.1 ± 3.5 (86.0)	0.471
hip-knee-ankle angle	-3.8 ± 5.5 (-3.1)	-3.6 ± 5.0 (-2.9)	0.707
Joint Line Convergence Angle	2.0 ± 2.3 (1.7)	2.3 ± 2.5 (2.3)	0.192
Mechanical Femorotibial Angle	5.9 ± 5.4 (5.5)	6.2 ± 5.3 (5.2)	0.394

Table 2. Comparison of Alignment Changes between Patients with and Without Minor Trauma

Parameter	No Trauma (n=27) Mean Change ± SD	Trauma (n=13) Mean Change ± SD	p-value*
Operated Side			
Δ LDFA (°)	-1.14 ± 3.07	+0.54 ± 2.16	0.034
Δ MPTA (°)	+0.10 ± 0.46	+0.47 ± 0.44	0.010
Δ HKA (°)	+1.23 ± 3.12	-0.07 ± 2.36	0.161
Δ JLCA (°)	+0.77 ± 1.97	-0.21 ± 1.55	0.149
Δ mFTA (°)	-0.39 ± 3.02	-0.98 ± 3.59	0.573
Contralateral Side			
Δ LDFA (°)	-0.09 ± 1.62	-0.09 ± 0.65	0.805
Δ MPTA (°)	+0.11 ± 1.46	+0.04 ± 0.57	0.391
Δ HKA (°)	+0.20 ± 2.36	+0.13 ± 1.05	0.776
Δ JLCA (°)	+0.35 ± 2.09	+0.22 ± 2.16	0.820
Δ mFTA (°)	+0.35 ± 2.86	+0.27 ± 2.87	0.475
***Mann-Whitney U test; statistically significant values (p < 0.05) shown in bold.**			

Discussion

The present registry-based analysis showed that total hip arthroplasty (THA) for hip disorders caused a small but statistically significant increase in MPTA on the operated side (mean change +0.3°, p = 0.008) at the two-month postoperative time point. However, the magnitude of this change (0.3°) is well below the threshold considered clinically meaningful for tibial alignment and is unlikely to affect knee joint biomechanics or osteoarthritis progression. No significant changes were observed in LDFA, HKA, JLCA, or mFTA, or in any parameters on the contralateral side. Furthermore, all alignment parameters on the contralateral, non‑operated limb remained stable. These findings suggest that THA does not meaningfully alter coronal limb alignment in the early postoperative period. Subgroup analysis revealed that patients with a history of minor trauma exhibited significantly different changes in LDFA and MPTA compared to those without trauma, despite the overall cohort showing no significant alignment changes. Specifically, the non-trauma group demonstrated a mean decrease in LDFA of -1.14°, whereas the trauma group showed a mean increase of +0.54° (p = 0.034). Similarly, MPTA increased more in the trauma group (+0.47°) than in the non-trauma group (+0.10°, p = 0.010). These differences, though statistically significant, are small in magnitude and may not be clinically meaningful. They could reflect pre-existing anatomical differences, variations in soft tissue tension, or differences in surgical reconstruction goals between patients with and without prior injury. Notably, we

observed no significant differences in HKA, JLCA, or mFTA changes between groups, suggesting that overall limb alignment remains stable regardless of minor trauma history. The comparable demographic characteristics between groups support that these findings are not confounded by age, BMI, or gender differences.

Comparison with existing literature

Our results contrast with several previous studies that reported varus shifts after THA. Choi et al. observed that the mean HKA on the ipsilateral side changed from 1.4° varus preoperatively to 2.7° varus at a minimum of five years post‐THA, and this change was associated with narrowing of the medial knee joint space [14]. Similarly, van Drongelen et al. found a mean varus change of approximately 1° and suggested that this could accelerate medial compartment knee osteoarthritis [19]. Ollivier et al. also reported a varus change of about 1.5° after THA, although they considered the biomechanical impact on the knee to be limited [6].

Several factors may explain why our results differ from these reports. First, follow‐up duration is a critical determinant. We assessed outcomes at two months, reflecting the direct early mechanical effect of the arthroplasty. In contrast, studies with longer follow‐up—such as the five‐year minimum in Choi et al.—inevitably incorporate the natural history of knee osteoarthritis progression and age‐related degenerative changes, which may contribute to late alignment shifts independent of the THA itself [14, 21].

Second, the patient population differs. Our cohort included patients with various hip disorders (e.g., post-major and minor traumas, osteoarthritis, avascular necrosis of the hip, Developmental Dysplasia of the Hip). In contrast, most published series focus on primary osteoarthritis or developmental dysplasia. The biomechanical environment after trauma—including pre‐existing deformities, scarring, and altered soft‐tissue tension—may respond differently to THA than degenerative conditions [2]. Third, surgical technique and implant choice vary across studies. Although our study did not specifically analyze implant design, the lack of significant alignment change suggests that the reconstructive goals (restoration of native femoral offset, neck‐shaft angle, and leg length) were achieved without inducing a systematic varus or valgus shift. For example, Rus et al. recently reported that two contemporary short‐stem designs did not significantly alter overall lower limb alignment or hip offset after THA [22]. Ortmaier et al. further showed that straight‐stem THA led to a higher rate of valgus deviation in the ipsilateral knee (57.2%) than short‐stem THA (29%), and that the degree of valgus was significantly greater with straight stems (8.9° vs. 6.4°) [23].

Role of femoral neck‐shaft angle and offset

The relationship between changes in femoral neck‐shaft angle (NSA) and postoperative limb alignment provides a mechanistic explanation for our stable findings. Choi et al. noted that a substantial reduction in NSA after THA was associated with a pronounced varus shift, and that patients with markedly decreased NSA showed greater HKA changes [14]. By contrast, Umeda et al. reported a valgus change after THA, which they attributed to the use of prostheses with a high NSA and decreased femoral offset [17]. In our cohort, the lack of significant NSA reduction likely contributed to preserving preoperative alignment. Moreover, femoral offset restoration—or its maintenance—has been shown to influence coronal alignment. Tanaka et al. found that increased femoral offset was independently associated with varus changes in dysplastic hip osteoarthritis, whereas decreased offset was linked to valgus changes [24].

On the non‐operated side, all alignment parameters remained stable. This finding is notable because some authors have reported compensatory changes on the contralateral limb after unilateral THA. Akasaki et al. found that changes in leg length discrepancy (LLD) after THA were significantly correlated with contralateral varus changes, particularly when the preoperative alignment was valgus or neutral [25]. In their study, the mean HKA change on the operated side was 0.8° varus, and this correlated with a change in JLCA—an indicator of intra‐articular load distribution. Our study did not observe a significant change in JLCA (from 1.8° to 2.2°, P = 0.222), further supporting overall stability of knee joint loading in our patients. Fujimaki et al. similarly observed that the contralateral knee tended to shift from varus toward neutral after THA, an effect they attributed to LLD correction [5]. In our study, we did not measure LLD directly; however, the absence of contralateral alignment changes suggests that any LLD present was either minimal or effectively corrected, and that no significant compensatory mechanism was triggered in the contralateral limb

within the three‐month follow‐up period.

Implications for traumatic hip disorders

Our study included patients with osteoarthritis, avascular necrosis of the hip, Developmental Dysplasia of the Hip, and post‐traumatic hip pathology, distinguishing it from many reports focused solely on primary osteoarthritis or developmental dysplasia. Trauma can lead to malunion, altered femoral offset, and limb length discrepancies that are often more complex than degenerative conditions. Nevertheless, our results indicate that with careful surgical reconstruction, coronal alignment can be restored to near‐preoperative levels without inducing deleterious changes on either side. This is clinically reassuring, because excessive varus alignment is known to accelerate medial knee osteoarthritis progression 10, 16, whereas valgus malalignment may predispose to lateral compartment disease.

Limitations

Several limitations should be acknowledged. First, the two‐month follow‐up is relatively short; longer‐term studies (e.g., five years or more) are needed to determine whether the observed stability persists or whether late alignment shifts occur due to implant‐bone adaptation or progressive osteoarthritis [21]. Second, our sample size was moderate (40 hips), and although we were powered to detect large differences, we may have missed smaller but potentially meaningful changes. Third, a single surgeon performed all measurements. While an interval of one month was used to reduce bias, we did not employ a fully independent blinded assessment. Finally, the single‐center design and involvement of multiple surgeons may limit generalizability, although this also reflects real‐world clinical practice.

Conclusion

In conclusion, this registry-based study shows that THA for hip disorders does not cause significant, clinically relevant changes in coronal lower limb alignment on either the operated or contralateral side after two months, and patients do not need early follow-up for malalignment. These results indicate that, in the early postoperative period, THA does not adversely affect knee alignment in patients with post-traumatic hip pathology. Clinicians can counsel patients that significant varus or valgus shifts of the lower limb are not an expected outcome of THA. Longer-term follow-up is warranted to confirm whether this stability persists over the years and to evaluate any potential late effects on knee osteoarthritis progression. However, this stability was assessed only at two months postoperatively; longer follow-up is essential to determine whether these findings persist over time or whether late alignment shifts occur due to progressive osteoarthritis, implant-bone adaptation, or other factors. The current results should not be interpreted as evidence of long-term alignment stability, and routine long-term monitoring for alignment changes remains warranted.

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Conflict of Interest Disclosures

The authors declare that they have no conflicts of interest related to this study.

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Authors’ Contributions

All authors contributed to the conception and design of the study. Clinical data collection and analysis were performed by the authors. All authors participated in drafting and revising the manuscript and approved the final version for publication.

Ethical Statement

Written informed consent was obtained from the patient and/or their legal guardian for publication of this case report and any accompanying images. All procedures were performed in accordance with the ethical standards

of the institutional and/or national research committee and the Declaration of Helsinki. Ethical Code: IR.BMSU.REC.1404.191.

Declaration of Generative AI and AI-assisted Technologies

The authors declare that no generative AI or AI-assisted technologies were used in the preparation, writing, or editing of this manuscript.

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