

Association of Leg Length and Femoral Offset Restoration With Functional Outcomes After Primary Total Hip Arthroplasty

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ABSTRACT

Background: Restoration of leg length and femoral offset is an important primary total hip arthroplasty (THA) goal but their relationship with postoperative functional outcome is not completely understood.

Objective: To explore the relationship between femoral offset, restored leg length and functional outcome after primary THA.

Material and Methods: This is a prospective observational analytical study conducted in the department of orthopaedics, Hayatabad Medical Complex, Peshawar from April 2022 to September 2022. Through consecutive sampling a total of 120 patients undergoing primary unilateral THA were included. Leg length and femoral offset were measured on the preoperative and the postoperative radiographs. The Harris Hip Score (HHS) was used to assess functional outcome pre- and 6 months following surgery. Descriptive and inferential statistics were carried out, such as correlation and multiple linear regression analysis.

Results: The mean age was 55.8 ± 10.7 years. Mean HHS improved from 45.7 ± 8.6 preoperatively to 86.9 ± 8.7 at six months ($p < 0.001$). Patients with leg-length restoration < 5 mm showed a significantly higher HHS than patients with a larger discrepancy (89.2 ± 6.9 vs. 81.8 ± 9.8 ; $p < 0.001$). Patients with a leg-length restoration of less than 5 mm had a significantly higher HHS than those with a greater discrepancy (89.2 ± 6.9 vs. 81.8 ± 9.8 ; $p < 0.001$). The same results were seen for the femoral offset restoration. The two variables were both separately correlated with postoperative HHS.

Conclusion: Restoration of leg length and femoral offset with accuracy was correlated to functional results after primary THA.

Keyword: Total Hip Arthroplasty (THA), Leg Length Restoration (LLR), Femoral Offset.

INTRODUCTION

Total hip arthroplasty (THA) has proven to be a successful treatment for end-stage hip disease and is primarily used for pain relief and to restore mobility and health related quality of life. However, the ability to restore a patient's native hip anatomy and biomechanics, in addition to positioning and fixation of the implant, is critical to a satisfactory postoperative result. Leg length and femoral offset are important anatomical parameters during THA as they relate to hip stability, muscle tension, gait mechanics and functional recovery^{1,2}.

Leg length restoration is a very important goal of primary THA. Limb length discrepancy (LLD) can occur as a result of existing hip disease or it may be created at surgery. Sizeable discrepancies may lead to patient dissatisfaction, changes to gait, pelvic obliquity and functional limitations; however, small discrepancies are clinically acceptable. However, over lengthening can lead to an increase in soft tissue tension, nerve irritation and perceived inequality. Thus, proper length of the limbs and hip stability is an important technical factor in THA^{2,3}.

Another key factor in the post-surgical biomechanics of the hip is the "femoral offset", which is the distance from the center of the femoral head to the femur's long axis. It helps to lengthen the abductor musculature's lever arm and affects soft tissue tension around the hip. If insufficient restoration of the femoral offset, especially excessive reduction, occurs, it can adversely affect the function of the abductors and lead to limp, gait asymmetry, decreased muscle strength, and functional results that are less than optimal^{4,5}. Modern surgeons have thus focused on the need to preserve as much as possible the normal femoral offset when performing THA^{5,6}.

Also, the length of the leg and its relationship to the femoral offset are very related to the hip reconstruction. All of these parameters can be altered simultaneously by changes in the femoral component position, neck length, size of the femoral head, and geometry of the implant. It is important to note, therefore, that the restoration of one anatomical variable

must not be regarded without considering the other. Reproducing the patient's native hip center, limb length and offset with implanting adequate stability is important: accurate pre-operative templating, appropriate implant selection and careful intraoperative assessment^{2,6}.

Restoring these parameters is clinically important and has been tested, both radiographically and patient-reportedly. In a prospective study of patients after primary hip arthroplasty, shorter femoral offset was linked to lower functional scores and increased gait irregularity and asymmetry, and postoperative leg length inequality to changes in pelvic movement during gait⁷. Likewise, there has been a link between implanting hip height and hip offset within about 10 mm of the native hip anatomy and improved Oxford Hip Scores and reduced postoperative pain⁸. The results indicate that there may be measurable implications for postoperative recovery based on anatomical reconstruction.

The association between radiographic restoration and functional outcome is not completely uniform throughout the literature, though. A systematic review of the literature on postoperative femoral offset found that the results were not consistent, with some studies showing favourable outcomes with restored, increased, and decreased offset, respectively⁴. A second systematic review showed that femoral offset was associated with polyethylene wear, but there were no consistent links with dislocation or implant loosening⁹. This variation could be due to differences between patient populations, definitions of acceptable reconstruction, implant design, measurement methods, and functional outcome assessment.

In addition, few studies have investigated leg length and femoral offset restoration at the same time and in the context of postoperative functional outcomes after primary total hip arthroplasty (THA), especially in the normal clinical population. While radiographic restoration is considered a significant surgical goal, how much deviation from native anatomy is associated with an important difference in functional recovery

remains unclear. This relationship may provide a better understanding of the clinical significance of postoperative radiographs measures and assist with more accurate surgical reconstruction.

Thus, the aim of the present study was to investigate the relationship between the restoration of leg length versus femoral offset and functional outcomes after primary THA. This study aimed to identify if there was any correlation between the restoration of leg length and femoral offset after primary total hip arthroplasty and the functional outcome.

MATERIAL AND METHODS

The data was collected through a period of six months (from April 2022 – September 2022) by conducting a prospective observational analytical study with the patients in the orthopaedics department of Hayatabad Medical Complex (HMC), Peshawar. The study investigated the correlation of leg length changes after primary total hip arthroplasty (THA) and the offset changes with functional outcomes.

During the study period, 120 patients with primary THA were included in the study consecutively. All patients aged 18 years and older with a primary unilateral THA and good pre- and post-operative radiographs and functional outcome assessment were included. Patients undergoing revision THA, bilateral THA, acute trauma or pathological fractures, active hip infection, malignancy and those patients who had poor radiographic or clinical follow-up were excluded.

Demographic and clinical data such as age, sex, body mass index (BMI), affected side, diagnosis and associated comorbidities were documented. The surgeries for all patients were performed as primary total hip replacement (THA) in the Orthopaedics Department in the standard manner. Information regarding the surgical procedure, surgical approach and implant characteristics were recorded. Preoperative planning and intraoperative evaluation were employed to help restore the hip joint to its native anatomy, including leg length and femoral offset.

Both preoperative and postoperative P-A pelvis radiographs were evaluated for leg length and femoral offset. Leg length was obtained by standardizing the radiographs with reference to certain landmarks and femoral offset was the perpendicular distance between the centre of rotation of the hip joint and the longitudinal axis of the femur. The postoperative measurements were compared with the appropriate native contralateral or preoperative measurements, to assess the degree of anatomical restoration. Residual leg-length discrepancy and difference in the femoral offset were then determined for each patient.

Harris Hip Score (HHS) was used for the evaluation of functional outcome. Preoperatively and 6 months postoperatively, the HHS was recorded along with pain, function, activities of daily living, gait, and ROM. The main functional result was the postoperative HHS, and the difference between the preoperative and postoperative HHS. The main radiographic parameters were the restoration of the leg length and the femoral offset.

All data were collected, entered and analyzed using IBM SPSS Statistics. The demographic, clinical, radiographic and functional parameters of the subjects were expressed in descriptive statistics. Continuous variables were presented as mean $\pm$ SD when normally distributed and as median (IQR) when not normally distributed, such as age, BMI, leg length, femoral offset and HHS. Categorical variables such as sex, affected side, underlying diagnosis and categories of leg-length and femoral-offset restoration were reported as frequencies and percentages.

A correlation between anatomical restoration and functional outcome was performed by inferential statistical analysis. Normally distributed continuous variables were compared with paired-samples t-test, and non-normally

distributed paired continuous variables were compared with Wilcoxon signed rank test. The independent-samples t-test or one-way analysis of variance (ANOVA) was used for normally distributed data, and the Mann-Whitney U test or Kruskal-Wallis test was used for non-normally distributed data, respectively, to assess differences in postoperative HHS based on the degree of leg-length or femoral-offset restoration. The association between the radiographic restoration and functional outcome was further analyzed using Pearson's correlation coefficient for normally distributed variables and Spearman's rank correlation coefficient for non-normally distributed variables.

To evaluate the ability of leg length and femoral offset to predict the postoperative HHS independently after controlling for other potential confounding variables, such as age, sex, BMI, and preoperative HHS, multiple linear regression analysis was performed. Confidence intervals for the regression coefficients were provided. A p value less than 0.05 was deemed as statistically significant.

Before the start of the study the study was approved by the relevant institutional ethical committee of Hayatabad Medical Complex with ethical approval number. All participants gave written informed consent. Confidentiality was respected during the study and all the data collected was only used for research.

RESULTS

A total of 120 patients who underwent primary total hip arthroplasty during the study period from January 2023 to June 2023 were included in the analysis. The mean age of the participants was 55.8 ± 10.7 years, with an age range of 32–78 years. There were 68 (56.7%) male and 52 (43.3%) female patients. The majority of patients were between 50 and 69 years of age. The mean body mass index was 26.4 ± 3.8 kg/m². The right hip was involved in 64 (53.3%) patients, whereas 56 (46.7%) underwent surgery on the left hip. The most common indication for THA was primary osteoarthritis, observed in 72 (60.0%) patients, followed by secondary osteoarthritis in 25 (20.8%), avascular necrosis in 18 (15.0%), and other indications in 5 (4.2%) patients (Table 1).

Radiographic assessment demonstrated substantial improvement in anatomical reconstruction following THA. The mean preoperative leg-length discrepancy was 8.6 ± 5.4 mm, which decreased to 3.1 ± 2.8 mm postoperatively. The mean absolute difference between postoperative and native leg length was 3.1 ± 2.8 mm. Similarly, the mean femoral offset was 39.8 ± 5.7 mm preoperatively and 40.7 ± 5.3 mm postoperatively. The mean postoperative deviation from the native femoral offset was 3.4 ± 2.9 mm. Overall, 82 (68.3%) patients had postoperative leg-length restoration within 5 mm, while 87 (72.5%) had femoral offset restoration within 5 mm. A combined restoration of both leg length and femoral offset within 5 mm was achieved in 72 (60.0%) patients (Table 2).

Functional outcomes improved substantially following primary THA. The mean Harris Hip Score increased from 45.7 ± 8.6 preoperatively to 86.9 ± 8.7 at six months postoperatively, representing a mean improvement of 41.2 ± 10.1 points ($p < 0.001$). Patients with leg-length restoration within 5 mm had a higher mean postoperative HHS than those with a residual discrepancy greater than 5 mm (89.2 ± 6.9 vs. 81.8 ± 9.8 ; $p < 0.001$). Similarly, patients with femoral offset restoration within 5 mm had a higher mean postoperative HHS compared with those with offset deviation greater than 5 mm (88.7 ± 7.4 vs. 82.1 ± 10.1 ; $p < 0.001$). The highest functional scores were observed among patients in whom both leg length and femoral offset were restored within 5 mm (Table 3).

Correlation analysis demonstrated significant inverse relationships between the magnitude of postoperative leg-length discrepancy and postoperative HHS, and between femoral offset deviation and postoperative HHS. Greater

residual leg-length discrepancy was associated with lower functional scores (Spearman's $\rho = -0.46$, $p < 0.001$), while greater deviation in femoral offset was also associated with lower HHS (Spearman's $\rho = -0.39$, $p < 0.001$). Multiple linear regression analysis demonstrated that both leg-length discrepancy and femoral offset deviation remained significantly associated with six-month postoperative HHS after adjustment for age, sex, BMI, and preoperative HHS. Each additional millimeter of leg-length discrepancy was associated with an estimated 0.82-point reduction in postoperative HHS, whereas each additional millimeter of femoral offset deviation was associated with an estimated 0.67-point reduction. Preoperative HHS was positively associated with postoperative functional outcome (Table 4).

The overall pattern of functional recovery according to the degree of anatomical restoration is illustrated in Figure 1. Patients with restoration of both leg length and femoral offset within 5 mm demonstrated the highest mean six-month HHS, whereas patients with deviations exceeding 5 mm in one or both parameters demonstrated lower postoperative functional scores.

Table 1: Demographic and Clinical Characteristics of the Study Participants (n = 120)

Variable	Category/Statistic	N	%
Age (years)	Mean $\pm$ SD	55.8 $\pm$ 10.7	—
Age (years)	30–39	10	8.3
	40–49	24	20.0
	50–59	34	28.3
	60–69	37	30.8
	≥ 70	15	12.5
Sex	Male	68	56.7
	Female	52	43.3
BMI (kg/m ²)	Mean $\pm$ SD	26.4 $\pm$ 3.8	—
BMI category	<25	43	35.8
	25–29.9	57	47.5
	≥ 30	20	16.7
Operated side	Right	64	53.3
	Left	56	46.7
Indication for THA	Primary osteoarthritis	72	60.0
	Secondary osteoarthritis	25	20.8
	Avascular necrosis	18	15.0
	Other	5	4.2
Preoperative HHS	Mean $\pm$ SD	45.7 $\pm$ 8.6	—

Table 2: Preoperative and Postoperative Radiographic Parameters

Radiographic parameter	Preoperative	Postoperative	Mean change/difference	p-value
Leg-length discrepancy (mm)	8.6 $\pm$ 5.4	3.1 $\pm$ 2.8	-5.5 $\pm$ 4.7	<0.001
Femoral offset (mm)	39.8 $\pm$ 5.7	40.7 $\pm$ 5.3	+0.9 $\pm$ 3.6	0.008
Absolute leg-length difference from native side (mm)	—	3.1 $\pm$ 2.8	—	—
Absolute offset difference from native side (mm)	—	3.4 $\pm$ 2.9	—	—
Leg-length restoration ≤ 5 mm	—	82 (68.3%)	—	—
Leg-length restoration >5 mm	—	38 (31.7%)	—	—
Offset restoration ≤ 5 mm	—	87 (72.5%)	—	—
Offset restoration >5 mm	—	33 (27.5%)	—	—
Both parameters restored ≤ 5 mm	—	72 (60.0%)	—	—

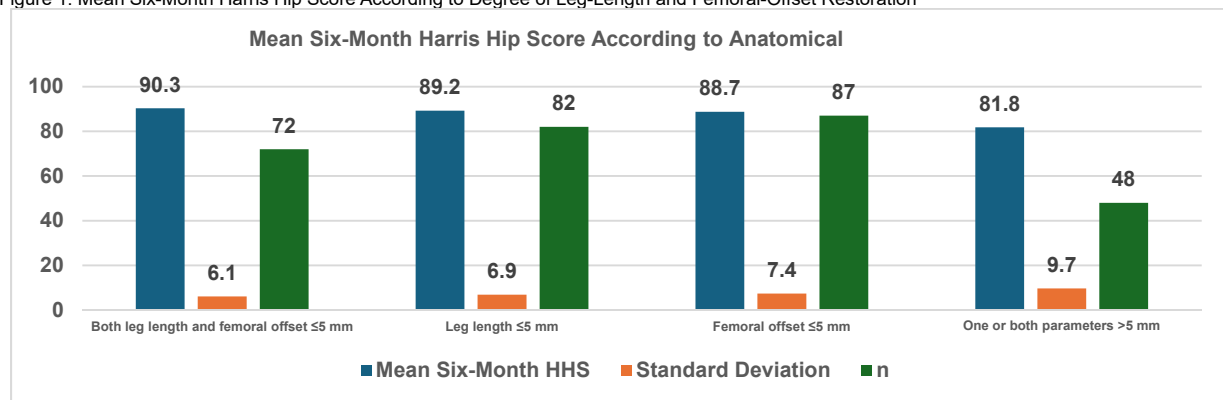
Table 3: Association of Leg-Length and Femoral-Offset Restoration With Functional Outcome

Restoration parameter	n	Preoperative HHS, mean $\pm$ SD	6-month HHS, mean $\pm$ SD	Mean improvement	p-value
Leg length ≤ 5 mm	82	46.1 $\pm$ 8.3	89.2 $\pm$ 6.9	43.1 $\pm$ 8.7	<0.001
Leg length >5 mm	38	44.8 $\pm$ 9.2	81.8 $\pm$ 9.8	37.0 $\pm$ 10.8	<0.001
Femoral offset ≤ 5 mm	87	45.9 $\pm$ 8.5	88.7 $\pm$ 7.4	42.8 $\pm$ 9.1	<0.001
Femoral offset >5 mm	33	45.2 $\pm$ 8.9	82.1 $\pm$ 10.1	36.9 $\pm$ 11.2	<0.001
Both ≤ 5 mm	72	46.3 $\pm$ 8.2	90.3 $\pm$ 6.1	44.0 $\pm$ 8.5	<0.001
One or both >5 mm	48	44.8 $\pm$ 9.1	81.8 $\pm$ 9.7	37.0 $\pm$ 10.7	<0.001
Overall	120	45.7 $\pm$ 8.6	86.9 $\pm$ 8.7	41.2 $\pm$ 10.1	<0.001

Table 4: Correlation and Multiple Linear Regression Analysis of Factors Associated With Six-Month Postoperative Harris Hip Score

Variable	Correlation with postoperative HHS (r/p)	p-value	Adjusted β coefficient	95% CI	p-value
Age	-0.18	0.048	-0.11	-0.25 to 0.03	0.126
BMI	-0.15	0.098	-0.21	-0.62 to 0.20	0.312
Sex	0.09	0.318	0.74	-1.42 to 2.90	0.501
Preoperative HHS	0.42	<0.001	0.38	0.18 to 0.58	<0.001
Residual leg-length discrepancy	-0.46	<0.001	-0.82	-1.18 to -0.46	<0.001
Femoral offset deviation	-0.39	<0.001	-0.67	-1.02 to -0.32	<0.001
Both parameters within 5 mm	0.43	<0.001	4.21	1.58 to 6.84	0.002

Figure 1: Mean Six-Month Harris Hip Score According to Degree of Leg-Length and Femoral-Offset Restoration



DISCUSSION

The present investigation assessed the relationship of restoration of the leg length and restoration of the femoral offset with the functional outcome after primary total hip arthroplasty. There was significant improvement in functional status in the present series of 120 patients with the mean Harris Hip Score rising from 45.7 ± 8.6 before surgery to 86.9 ± 8.7 six months after surgery. Additionally, post-operative radiographs showed good restoration of leg length and femoral offset. The higher the accuracy of the restoration of these parameters, the higher the functional scores obtained postoperatively. The results support the idea that native hip geometry needs to be restored as a critical part of a successful THA, but there has been some conflicting studies regarding the correlation between radiographic reconstruction and clinical results^{9,10}.

The mean leg-length discrepancy after surgery was 3.1 ± 2.8 mm with a mean discrepancy at the contralateral side being 8.6 ± 5.4 mm. Leg-length restoration was achieved in about 2/3 of the patients within 5 mm of the contralateral or native leg. The patients who had restoration within this range had a higher mean HHS at six months than patients with residual discrepancies more than 5 mm. This is in line with the evidence that clinically significant LE negatively impacts function and satisfaction post THA. Larger discrepancies after surgery, especially lengthening of around 10 mm or more, have been reported to be correlated with poorer functional outcome while smaller discrepancies may be without clinical significance^{11,12}. The association of postoperative LLD with patient-reported outcome measures is, however, not consistently shown; Whitehouse et al. did not find any significant association between postoperative LLD and patient-reported outcome measures in a group of 191 patients, indicating that the clinical significance of relatively small differences may be small¹³.

Clinically relevant findings of the current study are the improvement of leg length as there are other reconstructive goals to consider such as stability and soft tissue tension, which should be restored with leg lengthening. Too long will result in limb inequality and/or gait disturbance and in extreme situations neurological complications, while too short will lead to a loss in biomechanics. Another important message from the literature is the method-dependencies of radiographic measurement of LLD; different methods have varying reliability and validity¹⁴. Hence, the relatively strong correlation found in the present study is to be interpreted in the light of the measurement method employed. Standardization of the position and landmarks of measurement of the radiograph is significant if attempting to correlate relatively small differences in leg length to function.

In the present study, there was also a significant correlation between femoral offset restoration and postoperative function. A postoperative femoral offset within 5 mm of the native offset compared with more than 5 mm offset had a mean HHS of 88.7 and 82.1 respectively. In addition, there was an inverse correlation between the deviation from the normal femoral offset and the postoperative HHS. This is biologically plausible as femoral offset affects the abductor lever arm, tension in the soft tissues, hip stability and gait mechanics. Undercorrection of femoral offset has been shown in previous prospective work to be correlated with less satisfactory patient-reported function and changes in gait, but the correlation was weak⁹. Likewise, a systematic review revealed that restoration of the femoral offset might be correlated with better patient-reported outcomes, although the evidence was divergent¹⁵.

The present findings are provided by combining the analysis of leg length and femoral offset. Patients with both parameters restored within 5 mm also had the highest mean

postoperative HHS of 90.3 ± 6.1 , whereas those with one or both parameters being more than 5 mm off had a mean HHS of 81.8 ± 9.7 (multiple regression analysis, age, sex, BMI and preoperative HHS were adjusted for). This is similar to the prospective study by Innmann et al., who found an additive effect of hip offset and leg-length reconstruction on improvement in clinical outcome following primary THA. They concluded that higher improvement in HHS was related to accurate reconstruction of both parameters¹⁰. Later studies have also highlighted the importance of taking account of the combined effect of offset and leg length, rather than these being viewed as separate radiographic factors¹⁶.

However, the correlation of anatomical restoration with functional outcome is still complex. Some studies have not found clinically significant benefits to restoring the femoral offset or limb length. A study comparing global femoral offset revealed that there was no consistent association with patient-reported hip function, but that decreased offset was linked to decreased abductor muscle strength¹⁷. In another study, there was no consistent relationship between patient-reported measures and reduction of femoral offset smaller than 20 mm, although larger reductions (more than 20 mm) were associated with poorer pain and motion outcomes¹⁸. Likewise, radiographic parameters have been found to be inconsistent predictors of pain, function, and satisfaction in studies examining postoperative radiography, and factors like rehabilitation, muscle strength, implant positioning, preoperative disability, comorbidities, and patient expectations have also been shown to significantly impact recovery¹⁹. Therefore, the current results are interpreted as association rather than the conclusion that the only basis for functional recovery is radiographic restoration.

Intraoperatively, the findings highlight the importance of implementing a systematic planning process and monitoring during primary THA. By careful templating, implant selection, preservation of anatomical landmarks and, where possible, comparing the implant to the contralateral hip, leg length and femoral offset can be restored. There are examples from previous research that show that modern planning and navigation methods can obtain high accuracy in reconstruction of leg length and hip offset²⁰. The objective, however, does not have to be a perfect replica of each anatomical dimension, at the price of implant stability or other surgical aims. On the contrary, a restoration within a clinically acceptable range and soft-tissue balance, with an appropriate positioning of components, could be the most appropriate reconstruction strategy.

Limitations: There were a number of limitations in this study. The study was first undertaken in one tertiary-care center, with a relatively small sample of 120 patients, which may limit the generalizability of the results to other patients and centers. Second, the follow-up period was six months, and it is unclear whether the association between radiographic restoration and functional outcome is present at the longer term. Third, the radiographic measurements were taken from the plain pelvic radiographs, which can vary in position, pelvic rotation, magnification, and measurement technique. Fourth, the regression analysis controlled for several potential confounding factors, but other factors that could have an impact on functional recovery were not fully assessed, such as the approach used for surgery, the design of the implant, rehabilitation compliance, muscle strength, and patient expectations. Last but not least, the observational study design allowed for association but not causation. Additional multicenter prospective trials with more patients, uniform radiographic length measurements, longer follow-up and more validated patient-reported outcome measures would be beneficial to establish clinically relevant thresholds for leg-length and femoral-offset restoration after primary THA.

CONCLUSION

There was a significant association between restoration of leg length and restoration of femoral offset with functional outcomes after primary total hip arthroplasty. There were higher Harris Hip Scores at six months post-operatively and improvement in function in patients with less deviation in both parameters from the native anatomy. After controlling for pertinent patient characteristics, the residual discrepancy in leg length and deviation in the femur offset were independently associated with poorer functional outcomes. The results emphasise the value of correct pre-operative planning, selection of the implants and careful intraoperative assessment to obtain a satisfactory restoration of hip biomechanics. However, radiographic reconstruction should be evaluated in consideration of other variables which can affect the postoperative recovery such as preoperative functional status, rehabilitation, muscle strength, etc., and patient characteristics.

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