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Manuel Becerra, Enrique Cifuentes, Carolina Becerra, Nicolás Rojas, Francisco Cortés, Eduardo Maza, Leonardo Villarroel, Patricio Pincheira & Héctor Foncea

Hip Offset Parameters and Functional Outcomes Following Total Hip Arthroplasty: Association with Performance, Strength, and Patient-Reported Outcomes

Manuel Becerra (1), Enrique Cifuentes (1,2), Carolina Becerra (1), Nicolás Rojas (1), Francisco Cortés (1), Eduardo de la Maza (1), Leonardo Villarroel (1), Patricio Pincheira (3), Héctor Foncea (1)

(1) Hip Surgery Unit, Instituto Traumatológico Dr. Teodoro Gebauer Weisser, Chile.

(2) Department of Medical Education, Universidad de Chile.

(3) School of Health and Medical Sciences, University of Southern Queensland, Australia

Keywords: Total hip arthroplasty, Hip offset, Timed up and go test, Hip abductor strength, Pain assessment, WOMAC

Corresponding author:

Patricio Pincheira

School of Health and Medical Sciences, University of Southern Queensland

Patricio.pincheira@unisq.edu.au

ABSTRACT

Background:
Restoring native hip offset is considered important for optimizing function following total hip arthroplasty (THA), yet the relationships between offset parameters and postoperative outcomes remain inconsistently reported. This study investigated the associations between femoral offset (FO), acetabular offset (AO), and global offset (GO) with functional mobility, hip abductor strength, and postoperative pain.

Methods:
A total of 69 patients (mean age: 69.6 years) with unilateral THA were assessed at an average follow-up of 3.3 years. Offset parameters were measured radiographically and classified as decreased, restored, or increased relative to the contralateral hip. Functional outcomes were assessed using the Timed Up and Go (TUG) test and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Hip abductor strength was measured via manual dynamometry, and pain was evaluated using a visual analog scale (VAS).

Results:
No significant associations were found between offset parameters and TUG or WOMAC scores. However, patients in the decreased GO group exhibited significantly reduced hip abductor strength in the operated limb, with this asymmetry persisting over time. Additionally, both FO and AO in the non-operated hip were significantly associated with VAS pain scores, and their combined effect appeared to amplify pain perception. These relationships also changed over time during the follow-up period.

Conclusions:
While offset restoration did not relate to global functional tests such as TUG or WOMAC, patients with decreased global offset exhibited persistent abductor weakness, and contralateral offset parameters were associated with pain perception. These findings highlight the complexity of the relationship between offset and functional recovery and emphasize the importance of accurate offset restoration and bilateral biomechanical assessment in optimizing long-term outcomes following THA.

Keywords:

Keywords: Total hip arthroplasty, Hip offset, Timed up and go test, Hip abductor strength, Pain assessment, WOMAC

BACKGROUND

In Total Hip Arthroplasty (THA), the femoral offset (FO) is fundamental for restoring proper joint biomechanics. FO is defined as the distance from the center of rotation of the femoral head to the longitudinal axis of the femur, and a reduction in this parameter has been linked to suboptimal outcomes. Multiple studies have established that maintaining FO close to native anatomy improves functionality, while reductions beyond this threshold negatively impact biomechanics and clinical outcomes. For example, Cassidy et al. [3] demonstrated improved Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores when FO was maintained or increased. On the other hand, Sariali et al. [20] found diminished range of motion when FO was reduced by over 15% and Rüdiger et al. [19] Xu et al. [23] demonstrated that a reduced femoral offset alters the abductor muscle moment arm and increases both muscular demands and joint reaction forces. These findings highlight the critical role of FO preservation in optimizing both biomechanical efficiency and patient-reported outcomes after THA.

Acetabular offset (AO)—measured as the distance between the femoral head's center of rotation and either the center of the pelvis or the medial edge of the ipsilateral teardrop—has been less extensively studied. Clement et al. [4] observed that AO reduction is typically accompanied by FO increase, with AO alone having minimal influence on functional outcomes. However, Bonnin et al. [2] noted that excessive medialization may lead to impingement, bone stock loss, altered soft tissue tension, and reduced range of motion. Taken together, these findings suggest controversy regarding optimal acetabular offset.

Global offset (GO), the sum of FO and AO, has demonstrated significant correlations with clinical outcomes. Mahmood et al. [11] found that GO reduction greater than 5 mm is associated with diminished hip abductor strength, while Cassidy et al. [3], Clement et al. [4], and Weber et al. [22] linked decreased GO to reduced range of motion, increased need for orthopedic aids, gait asymmetry, and lower WOMAC scores. Robinson et al. [18] reported higher dislocation rates in patients with decreased GO and Renkawitz et al. [17] demonstrated that patients with restored GO (±5 mm) exhibited better gait speed and range of motion than those with increased GO. Thus, this threshold of ±5 mm could be seen as a clinically meaningful boundary

for categorizing GO variations relative to native anatomy, providing a standardized framework for evaluating the biomechanical and functional impacts of offset alterations. Surprisingly, however, standardized functional assessments of GO restoration's impact on patient mobility and rehabilitation outcomes remain limited.

The Timed Up and Go (TUG) test, a simple, low-cost mobility assessment, has demonstrated excellent reliability in THA patients and provides a valuable measure of functional mobility and recovery: it helps detect deficits in gait and balance before and after surgery, serves as a predictor of hospital stay duration, and can indicate clinically meaningful improvements in patient outcomes [6,14,16]. Hip abductor strength is another key functional indicator during post-THA rehabilitation, with manual dynamometry providing a reliable measurement method [13,21]. These objective functional tests provide direct assessment of biomechanical restoration by quantifying muscle function and dynamic movement patterns that directly reflect the altered joint mechanics resulting from offset modifications. Notably, despite the growing recognition of GO as a key determinant of postoperative biomechanics, few studies have directly examined its relationship with hip abductor strength, and none have correlated GO with TUG test outcomes.

The primary aim of this study was to investigate the association between hip offset parameters— FO, AO, and GO—and functional performance as measured by the TUG test. We also aimed to evaluate the relationship between these offset parameters and hip abductor strength in both the operated and non-operated limbs. Secondary objectives were to correlate hip offset parameters with patient-reported outcomes including the WOMAC and visual analog scale (VAS) pain scores. We hypothesized that patients with a decreased global offset—defined as a reduction of more than 5 mm from native anatomy—would demonstrate inferior TUG scores, reduced hip abductor strength and poorer functional outcomes compared to those with restored or increased offset values. Establishing clear relationships between offset parameters and functional performance could support surgeons in determining optimal component positioning and offset targets during THA, while also helping clinicians to develop more targeted rehabilitation strategies for patients with specific offset profiles.

METHODS

Study Design and Participants

This study was designed as a retrospective cohort study with cross-sectional functional assessment at follow-up. Patients who underwent total hip arthroplasty between 2015 and 2019 at the Traumatology Institute of Santiago, Chile, were evaluated once at a mean follow-up of 3.3 years postoperatively. All outcomes were collected at this single time point. Patients meeting the following inclusion and exclusion criteria were invited to participate in the study. Inclusion criteria encompassed individuals of all ages who had undergone THA for unilateral primary osteoarthritis and had a follow-up period exceeding one year. Exclusion criteria included secondary osteoarthritis, rheumatoid arthritis, prior lower limb arthroplasty, disabling degenerative damage to other joints, severe degenerative spinal pathology, history of spinal surgery, a body mass index over 40, or any condition precluding functional assessment. The study was approved by the hospital's Ethics Committee and conducted in accordance with the principles of the Declaration of Helsinki.

Eligible patients were contacted and, upon agreeing to participate in the follow-up evaluation, provided written informed consent. All participants had undergone postoperative rehabilitation following the hospital's standardised THA protocol, ensuring consistency in post-surgical care. During the follow-up, clinical and functional assessments were performed, including the administration of the WOMAC and VAS pain scores (i.e., global pain at the time of assessment), standardized radiographic imaging, hip abductor strength testing, and the Timed Up and Go (TUG) test. Demographic, clinical, and radiographic data were collected from both medical records and direct assessments.

Timed Up and Go Test

The TUG test was administered according to the protocol described by Podsiadlo and Richardson [16], a modified version of the test originally outlined by Mathias et al. [12]. Participants were instructed to rise from a 46 cm high armless chair, walk 3 meters in a straight line, turn around a marker, and return to sit down. The test was performed while wearing shoes and, if applicable, using their usual orthopedic aid. A

specialized physiotherapist conducted the measurements, with timing beginning when the patient's buttocks lost contact with the chair and ending when contact was re-established. The test was performed twice consecutively, and the average time (in seconds) of both attempts was used for data analysis.

Isometric Hip Abductor Strength

Isometric measurements of hip abductor strength for each lower limb were obtained using manual dynamometry (microFET®2, Hoggan Scientific, USA), which has demonstrated high intrarater and interrater reliability across various hip muscle groups [7]. Patients were tested in the supine position, with compensatory movements minimised by manual stabilisation of both the contralateral limb and the pelvis. This positioning was chosen because it provides high reliability and reduced variability in older adults [1]. The manual dynamometer was placed just proximal to the knee joint line on the lateral side, starting from a position of full knee extension and 0° hip abduction. Prior to the measurements, familiarization repetitions were conducted. Each subject then performed three maximal isometric contractions lasting 5 seconds each, with a 1 minute rest period between attempts. Force was recorded in Kilograms-force (kgf), and the primary variable analyzed was the peak force achieved across the three repetitions.

Radiographic Measurements

Anteroposterior pelvis radiographs were taken with patients in the supine position, both lower limbs internally rotated by 15º, at a distance of 115 centimeters, and with the focus centered on the pubic symphysis. All images were obtained using a 25-mm spherical marker positioned at the level of the greater trochanter for calibration; radiographs with calibration errors or suboptimal positioning were excluded. Measurements were performed by experienced hip and pelvis surgeons (each with at least 20 years of experience) using medical imaging software (MediCAD®2D, mediCAD Hectec GmbH, Germany). In line with Mahmood et al. [11], FO was measured as the distance between a line drawn along the longitudinal axis of the femur and the center of rotation of the native/prosthetic femoral head. AO was determined as the distance between the center of rotation of the native/prosthetic femoral head and a line perpendicular to the medial edge of the ipsilateral teardrop. GO was defined as the sum of FO and AO (Figure 1). Because preoperative images were unavailable, offset differences were calculated by subtracting the offset of the

operated hip from that of the contralateral, non-operated hip; thus, a negative value indicated that the offset was reduced relative to the native anatomy.

Measurements were performed by experienced hip and pelvis surgeons (each with at least 20 years of experience) using a medical digital imaging software (MediCAD®2D, mediCAD Hectec GmbH, Germany). A 25-mm spherical marker was positioned at the level of the greater trochanter to calibrate the scale. In line with Mahmood et al. [11], FO was measured as the distance between a line drawn along the longitudinal axis of the femur and the center of rotation of the native/prosthetic femoral head. AO was determined by measuring the distance between the center of rotation of the native/prosthetic femoral head and a line perpendicular to the medial edge of the ipsilateral teardrop. GO was defined as the sum of both distances (Figure 1). Offset differences were calculated by subtracting the offset of the operated hip from that of the non-operated hip; thus, a negative value indicated that the offset was less than the original.

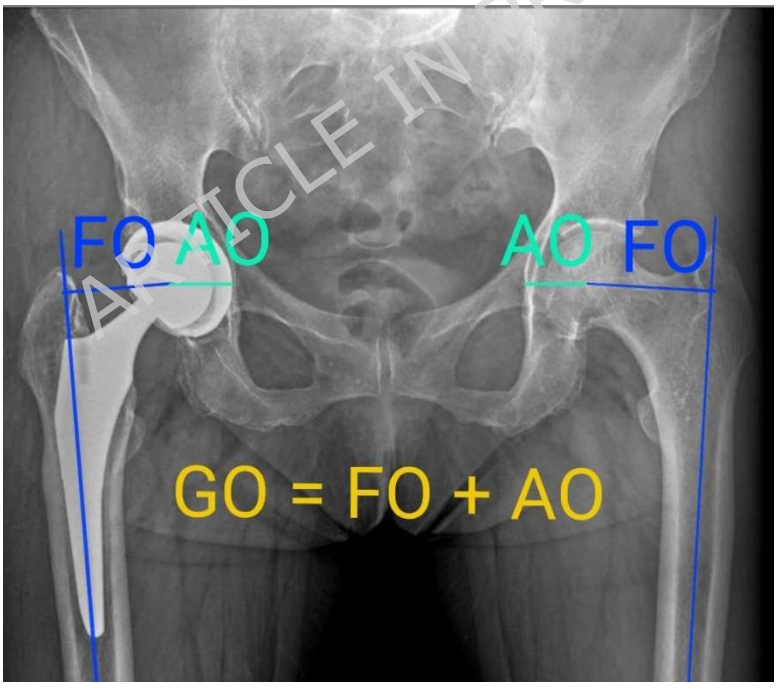

Figure 1. Anteroposterior pelvic radiograph illustrating the components of global offset (GO). Femoral offset (FO) was measured as the distance between a line drawn along the longitudinal axis of the femur and the center of rotation of the native/prosthetic femoral head. Acetabular offset (AO) was determined by measuring the distance between the center of rotation of the native/prosthetic femoral head and a line perpendicular to the medial edge of the ipsilateral teardrop. GO was defined as the sum of both distances.

Statistical Analysis

The associations between hip offset parameters and functional outcomes following THA were analyzed using linear and mixed-effects models. This approach was selected as it allows examining multiple predictors simultaneously (e.g., femoral and acetabular offset) and testing interactions between variables, allowing direct interpretation of how offset parameters influence functional outcomes. Based on our a priori hypothesis that decreased global offset would be associated with inferior functional outcomes, we conducted planned comparisons for each offset parameter, using the decreased offset group as the reference category. Global offset was categorized as decreased (> 5 mm reduction from native anatomy), restored (within ± 5 mm), or increased (> 5 mm increase) [17].

For the TUG, WOMAC and VAS scores, separate linear models were constructed for operated and non-operated hips. This separation acknowledges the distinct biomechanical characteristics of prosthetic versus native joints and enables direct assessment of how offset parameters differentially influence function in each hip. Each model incorporated follow-up time as a covariate to account for post-surgical duration.

Hip abductor strength measurements presented an inherent within-subject correlation, as each patient contributed paired measurements from both operated and non-operated sides. To account for this non-independence, we implemented a linear mixed-effects model with patient identifier as a random effect. This approach accommodated the paired data structure while maintaining the ability to test our hypotheses regarding global offset groups. The inclusion of interaction terms between offset parameters and operative status (operated vs non-operated) allowed us to examine how these relationships differed between hip joints, similar to the separate analyses conducted for the functional outcomes mentioned above. This model also incorporated follow-up time as a covariate to account for post-surgical duration.

Model assumptions were evaluated through Shapiro-Wilk normality tests of residuals. For models violating normality assumptions, we employed Cook's distance with a threshold of four times the mean to identify influential observations, followed by model refitting. Residual distributions and model stability were also visually inspected to ensure robustness across alternative parameterizations. Effect sizes were calculated

for all analyses to provide an indication of the practical importance of findings, irrespective of statistical significance. Effect sizes were quantified using Cohen's f^2 for continuous predictors (femoral and acetabular offset) and their interactions, with respective 95% confidence intervals. Values of $f^2 = 0.02$, 0.15, and 0.35 were interpreted as small, moderate, and large effects, respectively. For categorical predictors (global offset groups), Cohen's d with 95% confidence intervals was used to estimate effect sizes between decreased, restored, and increased offset groups, where $d = 0.2$, 0.5, and 0.8 represented small, moderate, and large effects, respectively. For hip strength measures, due to the mixed-model design, Cohen's d effect sizes were calculated for operated versus non-operated hip comparisons, offset groups and three-way interactions (group × hip × time), accompanied by their 95% confidence intervals. All statistical analyses were performed in R (v4.4.2) using lmerTest and emmeans packages, with statistical significance set at $p < 0.05$.

RESULTS

Out of a total of 1,241 records between 2015 and 2019, 100 patients met the inclusion and exclusion criteria. Of these, 69 agreed to participate in the study. The sample comprised 24 men (34.8%) and 45 women (65.2%), with an average age of 69.6 years (SD = 6.8). The surgical approaches were posterior (78%), lateral (14%), anterolateral (7%), and others (1%). The average follow-up period was 3.3 years. Fourteen patients (20.3%) routinely used a cane for ambulation. The FO of the operated and native hips was 41.5 mm and 37.9 mm, respectively, while the AO of the operated and native hips was 32.7 mm and 34.6 mm, respectively. The mean global GO in the operated hip was 74.2 mm compared to 72.5 mm in the native hip. The GO groups were distributed as follows: 50.7% restored, 30.4% increased, and 18.8% decreased. Descriptive statistics for key clinical and functional variables across global offset groups are summarized in Table 1.

Table 1. Descriptive statistics for clinical and functional outcomes stratified by global offset (GO) group.

GO Group	n	TUG median (IQR)	WOMAC median (IQR)	VAS mean (SD)	Strength Operated mean (SD)	Strength Non-operated mean (SD)
Decreased	12	11.0 (9.02–13.25)	5.8 (3.68–20.05)	1.17 ± 2.48	11.3 ± 2.54	12.4 ± 2.71
Restored	36	10.0 (8.97–11.83)	7.8 (3.93–14.30)	2.33 ± 2.98	13.8 ± 3.38	13.6 ± 3.38
Increased	21	11.2 (10.40–12.60)	8.3 (4.20–13.50)	2.95 ± 3.11	12.1 ± 2.36	11.9 ± 2.49

TUG, WOMAC, and VAS are reported as median (IQR) due to non-normal distribution. Strength variables are shown as mean ± SD. Groups are defined as follows: decreased (GO < –5 mm), restored (–5 mm ≤ GO ≤ 5 mm), and increased (GO > 5 mm). Strength values refer to hip abductor strength in kilograms-force (kgf). TUG = Timed Up and Go test (seconds); WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; VAS = Visual Analog Scale for pain (0–10).

TUG Test Performance

The TUG test results showed a mean time of 11.13 seconds (SD = 2.85), with a range from 7.40 to 21.08 seconds. Analysis of femoral and acetabular offset parameters revealed no significant associations with TUG test performance in either the operated or non-operated hips (Table 2). Similarly, when comparing TUG performance across offset groups (decreased, restored, or increased), no significant differences were

observed (Table 3). The effect sizes for between-group comparisons were small to moderate, with Cohen's d values ranging from 0.91 to 0.18, but none reached statistical significance.

Table 2. Association between hip offset parameters and functional outcomes in operated and non-operated hips.

Parameter	Operated Hip		Non-operated	
	f^2 [95% CI]	p-value	f^2 [95% CI]	p-value
TUG Test				
Femoral Offset	0.04 [0.01, 0.37]	0.58	0.05 [0.02, 0.39]	0.28
Acetabular Offset	0.02 [0.01, 0.28]	0.52	0.05 [0.02, 0.39]	0.30
FO × AO	0.01 [0.00, 0.14]	0.49	0.03 [0.00, 0.22]	0.23
FO × Time	0.01 [0.00, 0.13]	0.54	0.01 [0.00, 0.14]	0.49
AO × Time	0.01 [0.00, 0.14]	0.49	0.01 [0.00, 0.14]	0.52
FO × AO × Time	0.01 [0.00, 0.14]	0.45	0.01 [0.00, 0.20]	0.41
WOMAC				
Femoral Offset	0.06 [0.02, 0.39]	0.10	0.07 [0.03, 0.39]	0.12
Acetabular Offset	0.11 [0.04, 0.51]	0.09	0.08 [0.03, 0.42]	0.12
FO × AO	0.05 [0.00, 0.27]	0.10	0.04 [0.00, 0.26]	0.14
FO × Time	0.04 [0.00, 0.22]	0.15	0.02 [0.00, 0.18]	0.25
AO × Time	0.04 [0.00, 0.23]	0.16	0.02 [0.00, 0.20]	0.26
FO × AO × Time	0.04 [0.00, 0.24]	0.15	0.02 [0.00, 0.20]	0.25
VAS Pain				
Femoral Offset	0.10 [0.04, 0.47]	0.07	**0.24 [0.09, 0.72]**	**0.01***
Acetabular Offset	0.07 [0.02, 0.40]	0.07	**0.21 [0.09, 0.68]**	**0.01***
FO × AO	0.06 [0.00, 0.29]	0.06	**0.17 [0.04, 0.53]**	**0.01***
FO × Time	0.04 [0.00, 0.24]	0.13	**0.15 [0.03, 0.51]**	**0.01***
AO × Time	0.04 [0.00, 0.23]	0.14	**0.18 [0.04, 0.53]**	**0.01***
FO × AO × Time	0.04 [0.00, 0.23]	0.12	**0.17 [0.05, 0.54]**	**0.01***

Cohen's f^2 effect sizes with 95% confidence intervals are presented for the Timed Up and Go (TUG), WOMAC, and VAS pain scores. Analyses were conducted separately for the operated and non-operated

hips and include femoral offset (FO), acetabular offset (AO), and their interactions with follow-up time. Effect sizes were interpreted as small ($f^2 = 0.02$), moderate ($f^2 = 0.15$), and large ($f^2 = 0.35$). Statistically significant p-values ($p < 0.05$) are indicated with an asterisk (*).

Table 3. Between-group comparisons of functional outcomes across global offset (GO) categories.

Parameter	Effect Size d [95% CI]	p-value
TUG Test		
Decreased vs Restored	0.18 [-1.26, 1.62]	0.97
Decreased vs Increased	-0.73 [-2.27, 0.81]	0.63
Restored vs Increased	-0.91 [-1.98, 0.17]	0.23
WOMAC		
Decreased vs Restored	1.22 [-4.87, 7.30]	0.92
Decreased vs Increased	1.15 [-5.38, 7.67]	0.94
Restored vs Increased	-0.07 [-4.38, 4.24]	0.99
VAS Pain		
Decreased vs Restored	-1.77 [-4.26, 0.73]	0.35
Decreased vs Increased	-1.95 [-4.59, 0.68]	0.32
Restored vs Increased	-0.19 [-1.71, 1.33]	0.97

Cohen's d effect sizes with 95% confidence intervals are presented for comparisons between decreased, restored, and increased GO groups across the Timed Up and Go (TUG), WOMAC, and VAS pain scores. Effect sizes were interpreted as small (d = 0.2), moderate (d = 0.5), and large (d = 0.8). Statistically significant p-values ($p < 0.05$) are indicated with an asterisk (*).

Hip Abductor Strength

The mean abductor strength was 13.6 kgf in the operated hip and 14.1 kgf in the non-operated hip. In the decreased GO group, the comparison between the operated and non-operated hip, revealed a significant reduction in hip abductor strength on the operated side, with a large effect size (d = -1.23, p = 0.01) (Table 4). This pattern was not observed in the restored (d = 0.11, p = 0.65) or increased GO groups (d = 0.24, p = 0.45), indicating a distinct strength imbalance in the decreased GO group. The statistical analysis also revealed a significant three-way interaction between GO offset group, operative status, and follow-up duration (group × hip × time) for the decreased GO offset group (p=0.03, d=4.01) (Table 4). This interaction indicates that the strength relationship between operated and non-operated hips followed a different pattern of change over the follow-up period in the decreased offset group compared to the other groups. Specifically, operated hip strength in the decreased GO group remained consistently lower than the non-

operated side: operated hip strength was 11.1 kgf (SD = 3.0) at ≤38 months and 11.6 kgf (SD = 1.5) at >38 months follow-up, while non-operated hip strength increased from 11.9 kgf (SD = 3.1) to 13.3 kgf (SD = 1.6).

Between-group comparisons of hip abductor strength across offset categories revealed limited evidence of association (Table 4 under "Between Offset group Comparison" for both operated and non-operated hips). In the operated hip, patients in the decreased offset group showed a trend toward lower strength compared to those with restored offset (d = -2.00, p = 0.06), though this did not reach statistical significance. Similarly, patients with restored offset showed a trend toward lower strength than those with increased offset (d = 1.44, p = 0.09). In the non-operated hip, the restored offset group demonstrated higher strength than the increased offset group (d = 1.57, p = 0.05), though this borderline significant finding should be interpreted cautiously.

Table 4. Hip abductor strength comparisons by offset group, side, and time.

Comparison	Effect Size d [95% CI]	p-value
Between-Side Comparisons (Operated vs Non-operated)		
Decreased	**-1.23 [-2.13, -0.32]**	**0.01***
Increased	0.24 [-0.39, 0.86]	0.45
Restored	0.11 [-0.36, 0.58]	0.65
Between Offset group Comparison (Operated Hip)		
Decreased vs Restored	-2.00 [-3.72, -0.27]	0.06
Restored vs Increased	1.44 [0.11, 2.77]	0.09
Decreased vs Increased	-0.56 [-2.42, 1.31]	0.82
Between Offset group Comparison (Non - Operated Hip)		
Decreased vs Restored	-0.66 [-2.39, 1.07]	0.73
Restored vs Increased	1.57 [0.24, 2.90]	0.05
Decreased vs Increased	0.91 [-0.96, 2.77]	0.60
Offset Group × Time Interaction (Operated Hip)		
Decreased vs Restored	-3.06 [-9.21, 3.10]	0.33

Comparison	Effect Size d [95% CI]	p-value
Restored vs Increased	1.62 [-2.57, 5.81]	0.44
Decreased vs Increased	-1.44 [-7.89, 5.02]	0.66
Offset Group × Time Interaction (Non - Operated Hip)		
Decreased vs Restored	0.95 [-5.21, 7.10]	0.76
Restored vs Increased	-0.77 [-4.96, 3.42]	0.72
Decreased vs Increased	0.18 [-6.28, 6.64]	0.96
Three-way Interaction (Group × Hip × Time)		
Decreased	**4.01 [0.37, 7.65]**	**0.03***
Increased	-2.39 [-4.87, 0.09]	0.06
Restored	1.62 [-2.20, 5.43]	0.40

Cohen's d effect sizes with 95% confidence intervals are reported for: (i) operated vs non-operated hip comparisons within each GO group; (ii) between-group comparisons for operated and non-operated hips; (iii) offset group × time interactions; and (iv) three-way interactions (group × hip × time). Effect sizes were interpreted as small (d = 0.2), moderate (d = 0.5), and large (d = 0.8). Statistically significant p-values ($p < 0.05$) are indicated with an asterisk (*).

Patient-Reported Outcomes

The WOMAC score averaged 10.92 (SD = 10.40), ranging from 0 to 45.83. No significant associations were found when using femoral or acetabular offset measurements from either the operated or the non-operated hip as predictors of WOMAC scores. (Table 2). Similarly, when comparing WOMAC scores across GO offset groups, no significant differences were observed (Table 3).

VAS pain scores averaged 2.32 (SD = 2.96). Across global offset groups, VAS pain scores were: decreased offset group 1.17 (SD = 2.48, n = 12), restored offset group 2.33 (SD = 2.98, n = 36), and increased offset group 2.95 (SD = 3.11, n = 21), though these differences did not reach statistical significance (p = 0.25). In the non-operated hip model for VAS pain, significant associations were observed for both femoral and acetabular offset, showing moderate effects ($f^2 = 0.24$ and 0.21, respectively, p = 0.01). A significant interaction between femoral and acetabular offset was also observed ($f^2 = 0.17$, p = 0.01) (Table 2), suggesting that the combined influence of these offsets contributes to pain variability. Model coefficients

indicated that the relationship between offset and pain evolved over follow-up (femoral offset × time: β = 0.096; acetabular offset × time: β = 0.120), suggesting that the effect of offset parameters on pain changes over the recovery period. Although the three-way interaction (femoral offset × acetabular offset × time) was also significant (p = 0.01), its effect size was minimal (β = –0.003). Together, these findings indicate that offset restoration plays a role in early postoperative pain, but its influence becomes less pronounced during later recovery.

DISCUSSION

This study investigated the associations between hip offset parameters and functional outcomes following THA. Our findings partially support the hypothesis that a decreased global offset would be associated with poorer outcomes. While no significant associations were found between offset parameters and TUG performance, patients in the decreased GO group exhibited a marked deficit in hip abductor strength on the operated limb compared to the non-operated side, a pattern not observed in those with restored or increased offset. This strength asymmetry persisted over the follow-up period. Additionally, significant interactions were found between femoral and acetabular offset and VAS pain scores in the non-operated hip, indicating that these anatomical parameters influence pain perception in a combined manner. Despite these findings, WOMAC scores showed no significant associations with any offset parameters, highlighting a disconnect between patient-reported global function and anatomical restoration. Together, these results suggest that maintaining global offset within 5 mm of native anatomy may be important for preserving hip abductor function, but its influence on mobility and pain is more complex than initially hypothesized.

Offset values

Offset groups in this study were defined based on prior evidence suggesting that deviations greater than 5 mm from native global offset are associated with poorer outcomes in terms of hip stability and function [3,11,22]. In our sample, GO was restored in 50.7% of patients, increased in 30.4%, and decreased in 18.8%. While these proportions vary across studies, preoperative planning has been shown to improve restoration rates. The predominance of the posterior approach in our cohort (78%) may have influenced the observed offset distribution, as previous research indicates that surgical approach can affect the

restoration of FO and AO. Mean global offset measured 74.2 mm in the operated hip and 72.5 mm in the contralateral hip. Although normative GO values are not well established, our FO measurements (41.5 mm operated, 37.9 mm contralateral) align with previously reported population data [20].

TUG Test – Offset

To date, no studies have directly linked global offset to TUG performance. Our analysis revealed no significant associations between FO, AO, or GO parameters and TUG performance in either hip, contrary to our expectations given that offset restoration theoretically should influence functional mobility. Several factors may explain this finding. First, the TUG test is a composite measure involving multiple movement phases (sit-to-stand, walking, turning, and turn-to-sit) each potentially influenced by different anatomical and biomechanical factors beyond hip offset alone. Gasparutto et al. [6] demonstrated that while THA patients show deficits across all phases compared to healthy controls, the walking phase is most affected, suggesting that factors such as muscle strength, proprioception, and overall conditioning may be more influential than anatomical restoration alone. Second, our patients averaged 3.3 years post-surgery, allowing for significant compensatory mechanisms and neuromuscular adaptations that could mask the direct effects of offset variations on mobility. Third, the TUG test may lack sensitivity to detect the more specific biomechanical deficits associated with offset alterations, particularly when these are unilateral, as evidenced by the observable strength deficits in our decreased GO group. These findings suggest that while offset restoration remains important for hip mechanics, its influence on complex functional tasks like the TUG may be overshadowed by other factors in well-functioning patients at longer-term follow-up.

Abductor strength - Offset

Our findings revealed that patients with decreased global offset exhibited significantly reduced hip abductor strength in the operated limb compared to the non-operated side, a pattern not observed in the restored or increased GO groups. While the minimal clinically important difference for hip abductor strength is not universally defined, a side-to-side difference of approximately 10% is generally considered clinically relevant [8], as such asymmetry is associated with gait deviations and functional limitations. In our cohort,

mean inter-limb asymmetry reached about 9% in the decreased GO group and less than 2% in the restored and increased GO groups. This degree of asymmetry, persisting more than three years postoperatively, likely represents a clinically meaningful functional deficit resulting from inadequate offset restoration. These findings are consistent with those of Mahmood et al. [11], who reported a 22% abductor strength deficit between operated and non-operated limbs one year postoperatively in patients with GO reductions exceeding 5 mm. Reductions in offset have been shown to shorten the abductor moment arm and increase joint reaction forces [19], while excessive increases may compromise the function of other muscle groups [23]. Such biomechanical alterations likely underlie the strength deficits observed in our decreased offset group, reinforcing the importance of restoring offset within 5 mm of native values to optimise muscle function recovery.

Our study adds to this body of work by demonstrating, for the first time, that strength recovery trajectories differ over time depending on offset restoration. In patients with restored or increased GO, abductor strength in the operated limb improved and approached that of the non-operated side. In contrast, this recovery was absent in the decreased GO group. This differential recovery may reflect underlying biomechanical constraints. In adequately restored hips, optimal abductor moment arms facilitate normal strength recovery through rehabilitation and functional loading. However, in the decreased GO group, the persistent mechanical disadvantage from shortened moment arms impairs the muscles' ability to generate force effectively and adapt over time, preventing normal strength recovery despite adequate healing and rehabilitation. These findings underscore the long-term implications of inadequate offset restoration and highlight the need for further biomechanical investigations to understand the mechanisms driving persistent strength deficits.

Postoperative Pain – Offset

Interestingly, our analysis revealed that offset parameters in the non-operated hip significantly influence pain perception, highlighting a rarely explored aspect of THA recovery. Both femoral and acetabular offsets demonstrated moderate, statistically significant associations with VAS pain scores. Additionally, significant

interactions with follow-up time indicated that the relationship between offset restoration and pain evolved modestly during recovery, suggesting that offset-related effects on pain are more pronounced early after surgery and tend to diminish over time. This may be due to improved muscle tension, better joint load distribution, and reduced soft tissue irritation. A significant interaction between femoral and acetabular offset was observed, suggesting that these parameters influence pain synergistically rather than independently. Together, these findings may reflect compensatory mechanisms that emerge following unilateral THA. While some degree of contralateral loading is expected after surgery, patients with suboptimal offset restoration in the operated hip may exhibit more pronounced or prolonged compensation, placing greater biomechanical demand on the non-operated side. Biomechanical studies show that during gait in individuals with hip osteoarthritis and after THA, the non-operated limb often compensates by sustaining higher frontal-plane moments [5] and altered adduction kinematics [15]. In this context, a non-operated hip with larger femoral and acetabular offsets may provide a more favourable abductor lever arm and improved pelvic stability, which could reduce compensatory trunk sway, step-width adjustments, and perceived pain. Over time, this asymmetrical loading could lead to tissue strain, discomfort, or increased sensitivity. These findings highlight the complexity of pain mechanisms following THA and underscore the need for a more holistic understanding of how unilateral joint replacement affects bilateral lower extremity function and symptomatology. A more comprehensive assessment approach may benefit from evaluating contralateral biomechanics as part of pain management strategies.

Functional outcomes - Offset

The WOMAC score showed no association with variations in AO, FO, or GO in our study, highlighting the contradictory nature of existing literature on offset-functional outcome relationships. While numerous studies demonstrate that maintaining offset within ±5 mm of native anatomy improves WOMAC scores and functional performance [3,10,17], with deviations linked to poorer outcomes and altered gait patterns [20,22], other studies challenge these associations. Clement et al. [4] found that acetabular offset changes did not influence functional outcomes in 359 THA patients, despite consistent patterns of AO reduction and FO compensation. Additionally, measurement methodology may contribute to these contradictions, as

Lecerf et al. [9] demonstrated that radiographic measurements systematically underestimate femoral offset compared to CT scans, potentially affecting study conclusions. Our findings align with this uncertainty, suggesting that patient-reported functional outcomes may be influenced by factors beyond anatomical restoration alone, including rehabilitation protocols and patient expectations. In our cohort, the absence of association between offset and TUG or WOMAC performance may also reflect ceiling effects in well-functioning, long-term postoperative patients, where compensatory mechanisms (i.e., increased reliance on the contralateral limb, shorter step length, or cane use) may mask unilateral abductor weakness. This discrepancy between the persistent strength asymmetry observed in the decreased GO group and the absence of global functional differences underscores the complexity of defining optimal offset targets and the multifactorial nature of recovery following THA. Future studies incorporating stratified analyses by offset magnitude, surgical approach, or assistive device use could provide further insight into these compensatory adaptations.

This study has several limitations. Although the contralateral limb was used as a reference, it may not represent a truly healthy control, as residual deficits can persist even two years after surgery [8]. Caution is therefore warranted when interpreting the results, as this limitation could lead to an underestimation of the true between-limb differences. Our sample size, while sufficient for detecting moderate effect sizes, may have limited our ability to identify smaller associations. This limitation may be particularly evident in the decreased offset group (n = 12), where the heterogeneity relative to the non-decreased offset group (n = 57) could increase the risk of a type II error. Future studies with larger samples could further evaluate the stability of these findings. Offset measurements were obtained from standardized anteroposterior pelvic radiographs, which are known to underestimate true offset values by approximately 8% compared with CT-based assessments [20]. However, because our offset classification was based on delta values calculated within the same calibrated radiograph, this systematic underestimation would be consistent across participants, potentially attenuating true associations but unlikely to generate false-positive findings. The predominant use of the posterior approach (78%) at our center may limit the generalizability of our findings to centers using different surgical approaches. While our study followed a standardized post-operative rehabilitation protocol and excluded patients with disabling comorbidities (e.g., severe arthritis in other

joints, severe spinal pathology), we did not account for the potential confounding effects of minor/mild patient comorbidities not covered by the exclusion criteria (such as mild lower limb pain or low back pain). In addition, residual confounding related to preoperative condition and surgical decision-making factors that may influence both offset restoration and postoperative outcomes cannot be fully ruled out. Finally, our relatively long follow-up period (mean 3.3 years) may have allowed for significant compensatory adaptations that could mask the direct effects of offset variations on functional outcomes, particularly for measures like the TUG test. Despite these limitations, we believe our findings contribute to understanding the associations between offset parameters and patient-reported outcomes in a well-defined cohort with standardised perioperative care, which may inform future prospective studies designed to address confounding more comprehensively.

CONCLUSIONS

This study examined the relationship between hip offset parameters and postoperative outcomes following THA. Restoration of global offset emerged as the most critical factor for preserving hip abductor strength, whereas global mobility outcomes such as TUG and WOMAC appeared to be influenced by multiple interacting factors beyond offset parameters. Native offset in the non-operated hip also significantly influenced pain perception. Together, these findings highlight that while offset restoration is essential for optimal muscle function, overall functional recovery after THA likely reflects a broader interplay of biomechanical, neuromuscular, and clinical factors.

LIST OF ABBREVIATIONS:

- **THA**: Total Hip Arthroplasty
- **FO**: Femoral Offset
- **AO**: Acetabular Offset
- **GO**: Global Offset
- **TUG**: Timed Up and Go Test
- **WOMAC**: Western Ontario and McMaster Universities Osteoarthritis Index
- **VAS**: Visual Analog Scale
- **SD**: Standard Deviation
- **kgf**: Kilograms-force

- **CI**: Confidence Interval

DECLARATIONS

Ethics approval and consent to participate:
The study was approved by the ethics committee of Instituto Traumatológico Dr. Teodoro Gebauer Weisser.

Consent for publication
Not applicable.

Availability of data and materials
All data generated or analysed during this study are included in this published article and its supplementary information files.

Competing interests
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Authors' contributions
All authors contributed to the study design. HF and MB performed the radiographic analysis.
PP and HF wrote the manuscript and analysed the data. All authors contributed to data interpretation, reviewed manuscript drafts, and approved the final version of the manuscript.

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