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The modern state of femoral, acetabular, and global offsets in total hip arthroplasty: a narrative review

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- Offsets in the frontal plane are important for hip function.
- Research on total hip arthroplasty (THA) surgery agrees that increasing femoral offset up to 5 mm could improve functional outcome measures.
- The literature indicates that global offset is a key parameter that physicians should restore within 5 mm during surgery and avoid decreasing.
- Substantiated findings on acetabular offset are lacking despite its recognized importance, and the medialization approach must be assessed in light of its shortcomings.
- Future research, possibly through improved measurement, unified definitions, patient-specific surgical planning, and technology-enhanced surgical control, with specific focus on acetabular offset, is needed to better understand its impact on THA outcomes.

Keywords

- total hip arthroplasty
- offset

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Introduction

Total hip arthroplasty (THA) is among the most commonly performed surgical procedures to reduce pain and restore function in patients with hip disorders. Since its inception in 1960, this operation has steadily risen in demand, and there are now millions conducted each year (1). The majority of these surgeries are indicated for osteoarthritis but may also include cases of avascular necrosis of the femoral head, rheumatoid arthritis, traumatic arthritis, or other causes. Prior to surgery, patients most frequently complain of pain and loss of function (2, 3). In order to best meet patient expectations and improve patient satisfaction, these complaints must be closely monitored in patient outcomes.

The effectiveness and success rate of THA have historically been evaluated through the lenses of reoperation and complications, including infection and dislocation rates; however, with more recent studies, the evaluation has shifted to focus more on patient satisfaction and postoperative function with the use of patient-reported measure outcomes, capacity assessment in lab condition, and performance assessment in the real world (4). These outcomes are influenced by both patient-related factors such as age and comorbidities and implant-related factors ranging from component positioning to head–neck ratio. Orthopedic surgeons are scrutinizing more on specific geometric hip parameters that yield improved outcomes, as defined by the various former mediums. The primary goals of THA surgery, in accordance with the leading expectations, are to reduce pain whilst increasing function and quality of life (5, 6, 7). During THA, surgeons have control over the structure of the operated limb. Through a vast array of geometrical parameters, structure is linked with function, and both are related to daily living activities and quality of life as commonly identified relationships of the International Classification of Functioning, Disability and Health model (4, 7, 8, 9) established by the World Health Organization. Therefore, monitoring pre- and postoperative parameters on the ipsilateral and contralateral sides using radiographs or CT scan technology can help reach this objective by defining ideal ranges or relative ipsilateral/contralateral standards to improve patient function. Although not nearly an exhaustive list, important parameters that have been studied generally include those of the pelvis such as pelvic incidence, those of the femur such as limb length difference, and those of the cup and stem such as inclination/anteversion (10, 11, 12). One of these particularly crucial parameters that has received a great deal of research attention is offset.

All three definitions of offsets are depicted in Fig. 1 of the Appendix. Femoral offset is defined by the distance from the center of the femoral head to the line bisecting

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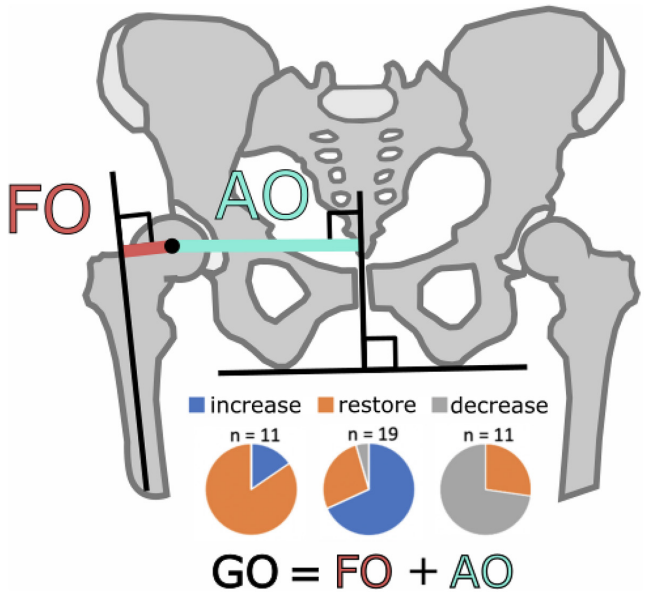

Figure 1
Literature recommendation (increase, restore, and decrease) overview on global, femoral, and acetabular offsets.

the long axis of the femur. For acetabular offset, there exist several definitions used by the literature that will be referred to in this study as the true floor offset and Pauwels offset. The former describes the distance between the center of the femoral head and the true floor of the acetabulum, whereas the latter refers to the distance from the acetabulum center to the center of the pelvis (13), also known as the body weight lever arm (14). Other definitions such as the anterior acetabular offset were not included in this review. Finally, the global offset describes the summed measurement distances of femoral and acetabular offsets. All three of these factors within the realm of offset have been recognized as important geometric parameters in patient outcomes. The primary purpose of this study is to summarize the current scientific knowledge on the femoral, acetabular, and global offsets in THA. A secondary goal of the narrative review is to propose future research that may enhance surgical practices through bettered representation of offset parameters (15).

Femoral offset

Within the boundaries of offset, this review will first cover the femoral component, for which numerous studies evaluate the risks and benefits of decreasing, increasing, or restoring femoral offset. Reducing femoral offset has generally been criticized by past research. Cassidy *et al.* (16) pioneered one of the prominent articles on this topic, finding that decreasing a patient's native femoral offset by more than 5 mm led to inferior functional outcome scores compared to the restored (–5 to 5 mm) and increased (>5 mm) offset groups. These findings were bolstered by Sariali *et al.* (17), who published that decreasing femoral offset can lead to alteration in gait. Rather than defining offset by length measurement they distinguished the decreased group (minimum 15% decrease) from the restored (within 15% change) and increased (minimum 15% increase) groups. The decreased group (mean –7.6 mm, range: –6 to –12 mm) had statistically significant asymmetry between sides, with reduced range of motion (ROM) and lower maximal swing speed of the limb during gait on the operated side (17). However, Robinson *et al.* (18) found that lower femoral offset was not associated with increased risk of dislocation. More recently, Rüdiger *et al.* (19) also reviewed other capacity outcomes in simulation and concluded that a decreased femoral offset leads to increased abductor muscle force and hip joint contact forces to maintain the hip abduction moment, in accordance with Pauwels biomechanical model of the hip (13). All of these studies thus argue that femoral offset should not be reduced during surgery. This is not to say there is unanimous agreement amongst the entire scientific community. Liebs *et al.* (20) contradicted the previous results, specifically those of Cassidy *et al.*, by publishing that low offset categorized patients reported less WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) pain than normal or high groups. However, the results of this study should be interpreted with caution since the offset groups are based on a theoretical offset determined with a linear regression between the height and the offset of patients that have weak correlation ($r=0.13$). An evaluation of the change in offset with respect to the pre-surgery ipsilateral or contralateral offset may have been more relevant and provided different results. Despite this study, it seems that the overwhelming majority of research warns against decreasing femoral offset (Table 1).

One of the most recent studies on femoral offset indicated that an increase of 2–3 mm in femoral offset could improve the abductor and external rotator function following THA while limiting impact on the rest of the hip function (21). Although statistically significant, these results had low determination coefficient values and assume that an increase in moment arm is equivalent to an increase in function. Other past studies have supported these results, such as Clement *et al.* (22) discovering that increased offset was significantly associated ($r=0.198$) with greater improvement in the Oxford hip score (OHS). For this reason, it seems that postsurgical increase of up to 5 mm may improve functional outcomes. Rüdiger *et al.* furthered this study by investigating not only muscle moment arms but also muscle and hip reaction forces. In simulation, increased femoral offset reconstructions were found to significantly increase muscle moment arms, which is associated with decreased forces acting

Table 1 Femoral offset – overview of key findings from the literature.

Study	Year	Cases	Type	Follow-up	Benchmark offset	Parameter related to offset	Key findings
Sakalkale *et al.* (24)	2001	17 bilateral THA patients	Prospective	5.7 years (range: 2–10.2)	Difference in offset between each side in bilateral THA	Acetabular polyethylene wear	Lateralization of the femoral component reduced polyethylene wear
Asayama *et al.* (14)	2005	30 patients	Retrospective	Minimum of 1.5 years	Comparison of normalized offsets between patients	Isometric hip abductor strength	Higher normalized offsets were associated with greater abductor strength and ability to perform the delayed Trendelenburg test
Lecerf *et al.* (23)	2009	Collection of seven studies, Study 6: 94 patients	Retrospective	Study 6: 6 years	Study 6: high offset femoral stem vs standard stem	Study 6: survival rate	
Cassidy *et al.* (16)	2012	249 patients	Retrospective	1 year	Contralateral offset	SF-12, WOMAC	Decreased femoral offset group (<5 mm) had lower WOMAC physical function score than restored (–5 mm to 5 mm) and increased femoral offset groups (>5 mm)
Robinson *et al.* (18)	2012	668 primary THA (580 patients)	Retrospective	3.4 years (range: 2– 6.6)	Contralateral offset	Dislocation (9/668 hips)	No difference between dislocation group ($n=9$) and non-dislocation group ($n=659$) for femoral offset only
Liebs *et al.* (20)	2014	362 patients	Retrospective	0.25, 0.5, 1, and 2 years	Linear regression between height and offset ($R2=0.13$)	WOMAC pain	Low offset group reported less pain on all timepoints
Sariali *et al.* (17)	2014	28 patients	Prospective	1 year	Preoperative ipsilateral offset estimated before the onset of osteoarthritis	Gait analysis, PMA, HHS, WOMAC, HOOS	Decreased offset group (mean –7.6 mm, range 6–12 mm) had significant asymmetry during gait contrary to restored and increased groups
Clément *et al.* (22)	2016	359 patients	Prospective	1 year	Preoperative ipsilateral offset	OHS, SF-12, EQ-5D-3L, satisfaction	Increasing femoral offset was associated with increased improvement in OHS ($r=0.198$, 95 % CI 0.063–0.333, $P=0.004$)
Rudiger *et al.* (19)	2017	15 hip OA patients	Simulation	NA – simulated implantation	Preoperative ipsilateral offset	Simulated abductor moment arms, simulated muscles, and joint reaction forces	During gait, a decrease in femoral offset leads to an increase in abductor muscle force and an increase in joint reaction force
Hu *et al.* (21)	2021	18 patients	Prospective	10.4 ± 4.9 months	Ipsilateral offset	Hip muscles lever arms during gait	An increase in FO of 2.3–2.9 mm resulted in increased abductor moment arms while maintaining the maximum decrease of the hip muscles at less than 5.0%

SF12,12-item Short Form Survey; PMA, Postel Merle d'Aubigné Hip Score; HHS, Harris Hip Score; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; HOOS, Hip Disability and Osteoarthritis Outome Score; OHS, Oxford Hip Score, EQ-5D-3L, 3-level version of the EuroQol five dimensions of health questionnaire.

on muscles and hips (19). In a similar study by Asayama *et al.* (14), optimal reconstructed hip function assessed via abductor muscle function appears to be achieved through a normal to a slight increase in femoral offset (Table 1).

Longevity is another surgical factor that must be considered. According to Lecerf *et al.* (23), 'femoral offset restoration is essential to improve the function and longevity of hip arthroplasty'. This may also be measured by the implant wear rate. That said, surgeons must still be wary of excessively increasing this parameter as high offset femoral stem may slightly decrease the implant survival rate (23). However, lateralization of the femur that restores offset better improves hip biomechanics and significantly decreases polyethylene wear (24). In theory, this should mean that the implant lasts for a longer amount of time without the need for revision surgery or replacement, marking another indicator of outcome success.

Overall, the literature seems to agree that decreasing femoral offset is detrimental, whereas increasing the

parameter within a reasonable range of 5 mm may improve patient outcomes.

Acetabular offset

The literature is sparser on the topic of acetabular offset relative to its femoral counterpart. In fact, there has been less interest and fewer published studies concerning acetabular offset (25). A recent study noted that most research has focused on femoral offset in relation to gait and function despite both femoral and acetabular offsets being considered important when restoring hip joint anatomy (26). Given the multiple possible definitions to define acetabular offset, any variation from the true floor offset definition will be specified since this is the most commonly accepted version.

For the available literature on acetabular offset, the long-held biomedical theory of medialization seems to be the most prominent model for improving patient outcomes (Table 2). This conventional acetabular preparation consists of reaming down to the true floor, which medializes the center of rotation of the hip and reduces the acetabular offset. This medialization decreases the lever arm of the body weight during monopodal stance, which lessens the resultant force on the femoral head if all else is constant (13, 25). Medialization has

Table 2 Acetabular offset – overview of key findings from the literature.

Study	Year	Cases	Type	Follow-up	Benchmark offset	Parameter related to offset	Key findings
Tripuraneni *et al.* (29)	2010	75 primary THA	Retrospective	1 year in average	Preoperative ipsilateral offset	Lower limb length discrepancy	Inferior acetabular positioning contributed most significantly to postoperative lower limb length discrepancy. Increased global offset was mainly due to lateralized acetabular component
Kurtz *et al.* (30)	2010	10 THA	Simulation	CT during surgery	Preoperative ipsilateral offset	Simulated hip arthroplasty ROMBI	Medialization of the acetabular cup reduced significantly the hip ROMBI. Acetabular offset had greater impact on ROMBI than femoral offset. Increase in femoral offset did not compensate decrease in acetabular offset regarding ROMBI
Bonnin *et al.* (25)	2012	100 normal hips	Simulation	NA – simulated implantation	Ipsilateral offset	NA	Large inter-individual variations of native acetabular offset. Medialization is of 1.6 mm ± 1.2 with the anatomical cup placement and 4.8 mm ± 1.9 with the conventional cup placement
Terrier *et al.* (33)	2014	15 patients	Simulation	NA – simulated implantation	Ipsilateral offset	Moment arms of the gluteus medius and minimus in simulated hip range of motion of gait	The increase of moment arms with decrease of acetabular offset, compensated by an increase in femoral offset, depends on the individual anatomy. Advantage of cup medialization may depend on the patient
Clément *et al.* (22)	2016	359 patients	Prospective	1 year	Preoperative ipsilateral offset	OHS, SF-12, EQ-5D-3L, satisfaction	Change in acetabular offset had no significant effect on the outcomes
Merle *et al.* (28)	2019	131 hip OA	Simulation	NA – simulated implantation	Ipsilateral offset	NA	Large inter-individual variations of native acetabular offset (up to 13 mm). Risk of excessive medialization up to 19 mm when reaming down to the true floor of the acetabulum
Zuo *et al.* (32)	2021	26 normal hips	Simulation	NA – simulated implantation	Ipsilateral offset	Simulated acetabular component coverage rate, micromotion, and peak stress distribution	Conventional technique has higher coverage rates, while anatomical technique has less micromotion and no stress concentration

ROMBI, range of motion before bony impingement; OHS, Oxford Hip Score; SF-12, 12-item Short Form Survey; EQ-5D-3l, 3-level version of the EuroQol five dimensions of health questionnaire.

been shown to improve THA survival and results in less contact stress (25). An early study of this mentioned that the native hip center of rotation should be restored or slightly medialized for optimal acetabular component coverage (23). This theory did in fact show improved functional outcomes when paired with compensatory increased femoral offset (22). According to Clement *et al.* (22), a significant increase in the femoral offset (5 mm) was associated with a significant decrease in acetabular offset (5 mm) due to medialization with no change in the global offset. Flecher *et al.* (27) outlined the likely scientific reasoning: 'a decrease in acetabular offset could exert beneficial effects by decreasing the stress applied to the prosthetic joint and would require counterbalancing by increasing the femoral offset to avoid decreasing the global offset which would require limb elongation to prevent instability' (Table 2). This hypothesis lacks specific references, though, and must be considered in light of this weakness. Another potential defect of this theory is that a substantial number of patients appear at risk for excessive cup medialization. Merle *et al.* (28) reported that reaming could lead to a clinically relevant reduction of acetabular offset greater than 8 mm, with patients observed at risk of excessive medialization up to 19 mm (Table 2). On the other hand, surgeons must also avoid incomplete medialization by still removing enough bone from the acetabular component. Such failure to appropriately medialize contributes to offset discrepancy and is a common error in the execution of templating resulting in increased global offset (29).

While most of the available literature focuses on decreasing acetabular offset in relation to femoral offset, there exist multiple critics of this guideline. In contrast, some authors would rather preserve the acetabular offset by maintaining a space between the true floor of the acetabulum and the acetabular cup (25). A simulation study by Kurtz *et al.* (30) found that the ROM before bony impingement decreased with decreased acetabular offset (Table 2). Moreover, changes in acetabular offset had a greater effect on ROM before bony impingement than changes in femoral offset, and this lost ROM with decreased acetabular offset was not fully recoverable with an increase in femoral offset. As opposed to traditional medialization with beneficial effects on joint reaction force, the advantages of restoring an anatomical position are increasingly recognized. The maintained acetabular offset offers advantages regarding the ROM before impingement, press-fit uncemented implants, and the preservation of medial bone stock (31). A decrease in acetabular offset corresponds usually to the standard technique of medialization of the cup by reaming the acetabulum within a safe zone defined for patients individually (31). Zuo *et al.* (32) recently compared in a simulation the acetabular component coverage rates for the conventional reaming technique, i.e. reaming to the true floor, and anatomical technique, i.e. reaming to the subchondral bone. In this proposal, orthopedic surgeons ream the acetabulum medial to the floor until a suitable component size for implantation is achieved (Table 2). This results in medial and superior displacement of the rotation center, so as to obtain the approximate normal acetabular offset and the center of rotation of the hip. Results showed that the coverage rates were higher with the conventional technique than the anatomical technique which led to less micromotion and reduced stress concentration (32). Although these boundaries can be helpful, medialization remains very variable across patients (33) and must be balanced against its trade-offs, including the additional loss of medial acetabular bone stock, and eventual proprioceptive implications of the nonanatomic center of rotation and perhaps joint reaction forces in this case per Pauwels offset definition. Contrary to the femoral offset, there is currently no agreed range on the medialization of the acetabular cup.

Global offset

Research continues to put greater emphasis on global offset, the sum combination of the femoral and acetabular components, as an essential factor when considering its subsets in the realm of offset. Biggi *et al.* (34) underline that, since the global offset takes into account both acetabular and femoral offset, it is a more reliable joint parameter when restoring hip parameters after primary THA than femoral offset alone (Table 3). Because femoral and acetabular offsets may be individually changed, however, this raises a question about whether the overall global offset should be resultingly decreased, increased, or maintained.

The decrease of global offset has been examined and criticized in several studies and is often cited as a surgical error. For instance, Mahmood *et al.* (35) cautioned that reducing global offset by more than 5 mm has a negative association with patient functional outcomes (Table 3). According to this study, patients with decreased global offset had worse function estimated with the WOMAC, less abductor strength, and more use of walking aids (35). Differences larger than 5 mm relative to the contralateral hip appear to have a negative impact on gait (36). Furthermore, increased dislocation risk was seen in a majority of hips that had a reduced global offset (18) (Table 3). Weber *et al.* (37) also addressed this in a study showing that 20% fewer patients were able to fulfill ROM criteria required for activities of daily living (ADL) when offset was not fully restored (Table 3). It generally seems that surgeons should avoid decreasing global offset where possible, then, given that only negative results have been identified.

Table 3 Global offset – overview of key findings from the literature.

Study	Year	Cases	Type	Follow-up	Benchmark offset	Parameter related to offset	Key findings
Kurtz *et al*. (30)	2010	10 THA	Simulation	CT during surgery	Preoperative ipsilateral offset	Simulated hip arthroplasty, ROMBI	Increase in femoral offset did not compensate decrease in acetabular offset regarding ROMBI
Tripuraneni *et al*. (29)	2010	75 primary THA	Retrospective	Average: 1 year	Preoperative ipsilateral offset	Lower limb length discrepancy	Increased global offset was mainly due to lateralized acetabular component
Robinson *et al*. (18)	2012	668 primary THA	Retrospective	3.4 years (range: 2–6.6)	Contralateral offset	Dislocation (9/668 hips)	Majority of hips that dislocated ($n=9$) had decreased global offset (–5.7 mm, $P=0.042$)
Mahmood *et al*. (35)	2016	250 patients	Retrospective	1 year	Contralateral offset	WOMAC, EQ-5D, hip abductor muscle strength	Decreased global offset group (<5 mm, mean –12.8 mm) had lower hip abductor muscle strength and WOMAC scores
Clément *et al*. (22)	2016	359 patients	Prospective	1 year	Preoperative ipsilateral offset	OHS, SF-12, EQ-5D-3L, satisfaction	Increasing global offset was associated with increased improvement in OHS ($r=0.1$, 95% CI: 0.01–0.19, $P=0.04$). Global offset seemed not as important as femoral offset
Biggi *et al*. (34)	2020	80 patients	Retrospective	4.4 years (range: 3.2–5.7)	Preoperative ipsilateral offset	NA	ΔGO within ±5 mm range. The use of a 3-offset femoral stem was effective in restoring native global offset
Weber *et al*. (37)	2020	121 patients	Prospective	6 weeks	Contralateral offset	Simulated hip range of motion before impingement	In patient with high offset stems, simulated under restoration led to a decrease of more than 20% of patients fulfilling ROM criteria required for ADL. In patients with standard offset stems: simulated over restoration of offset lead to negligible increase of less than 10%
Esbjornsson *et al*. (26)	2021	65 patients	Prospective	1 year	Preoperative ipsilateral offset and contralateral offset	HOOS, EQ-5D, gait analysis	Improvement in gait pattern, pain, HOOS, and EQ-5D with restored global offset based on medialized acetabular offset and increased femoral offset. Increase in hip adduction moment not associated with change in femoral/acetabular offset quota but with more upright posture (less trunk lean and pelvic obliquity) and increased walking speed
Ohmori *et al*. (38)	2021	91 patients	Prospective	CT scan: 2 weeks; functional tasks, 1 year	Preoperative ipsilateral offset	Gait speed	Global offset was not a significant factor in postoperative gait speed

ROMBI, range of motion before bony impingement; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; EQ-5D, EuroQol five dimensions of health questionnaire; OHS, Oxford hip score; SF-12, 12-item Short Form Survey; EQ-5D-3L, 3-level version of the EuroQol five dimensions of health questionnaire; HOOS, Hip Disability and Osteoarthritis Outome Score; ROM, range of motion; ADL, activities of daily living.

When evaluating the premise of restoring or increasing global offset, the literature seems more relatively supportive as compared to decreasing it. Some articles (Table 3)have argued for the restoration of global offset by orthopedic surgeons (17). There is evidence to show that this benefits patients' postoperative outcomes. Indeed, Esbjörnsson *et al.* (26) showed improvements in gait pattern, pain, and health-related quality of life when global offset was adequately restored based on decreased acetabular offset per Pauwels definition and increased femoral offset. Interestingly, Clement *et al.* (22) also showed that a significant decrease in acetabular offset and increase in femoral offset and hence no overall significant change in global offset yields improved functional outcomes. Despite the insignificant change in global offset, increasing offset was associated ($r=0.10$) with a greater improvement in the OHS (22). However, within the restoration of global offset, the respective increase and decrease of acetabular and femoral offset should be taken into account. Indeed, Kurtz *et al.* (30) showed that an increase in femoral offset did not compensate for the decrease in acetabular offset regarding the simulated ROM before impingement. Increasing offset above standard restoration has also shown a positive – albeit negligible – increase of less than 10% of patients fulfilling ROM criteria for ADL (37). One study additionally indicated that global offset was primarily increased due to the lateralized acetabular

component, an interesting consideration giving more reason to focus on this parameter (29). Thus, on the topic of global offset, it seems as though it should be restored overall, that is at least within 5 mm in either direction, and that surgeons should avoid decreasing this parameter given its potential to generally worsen patient outcomes. For certain functional outcomes, however, such as postoperative gait speed, global offset may not be a significant factor (38).

Findings and Discussion

Based on this narrative review, we conclude that the current state of offset adjustments by surgeons yields a reduction in postoperative acetabular offset and increased femoral offset to maintain global offset (39). That said, of these factors, acetabular offset is most overlooked both in the literature and thus quite possibly also in surgical practice with clinical consequences. This suggests that femoral offset is being prioritized as a parameter. To improve future research, it is important to investigate why acetabular offset has received relatively less focus than femoral and global offsets to date.

The first reason that acetabular offset may be less studied is that this offset is difficult to measure, particularly on standard x-rays (40). Even the more studied femoral offset component may be underestimated by up to 20% on radiographs and thus not restored, with clinical consequences (17). We thus hypothesize that the acetabular component might therefore have even less reliable estimates, given that it is more often neglected.

An additional explanation for this may be related to the fact that there is not a uniform definition that is widely accepted as in the case of femoral offsets. As written in the introduction, the literature in our review included two different types and acknowledged the existence of others in addition. The multiple definitions yield varying lengths for the same term and make it harder for researchers to reference and cross-examine studies when the basis of evaluation is changing. Global offset is likewise affected, given that its sum value includes acetabular offset. Clinical consequences might follow if some surgeons are relying on results from varying definitions or are not appropriately measuring the offset. The homogenization of definitions should also encompass the evaluation of the change in offset since studies use multiple definitions.

The next consideration for the absence of literature on acetabular offset could be that the acetabulum anatomy itself has great variability (28). Acetabular offset widely varies between individuals, and the acetabular floor distance can be up to 13 mm, which needs to be considered for surgery (25). While femoral offset's larger size is a factor, such variance may explain why studies reveal no correlation between the changes of acetabular and femoral offsets despite significant correlation between femoral and global offsets (41). Anatomical variance adds further complications to outlining target parameter lengths, which is already difficult given that no two hips are the same. Moreover, the resultant hip center of rotation following THA is influenced by both the acetabular anatomy and the surgical technique used to implant the acetabular component (25).

A final factor contributing to our lack of knowledge regarding acetabular offset may be related to surgeon control. The surgeon's ability to control measurement and error may relate to the greater size of femoral offset or the need to use a hammer in adjusting the acetabular cup. In general, depth of the acetabular component is much more difficult to alter than other parameters such as cervico-diaphyseal angle and neck length. These rationales might explain why the acetabular offset is often changed in relation to the femoral offset to restore global offset. Liebs *et al.* (20) hypothesized that the surgeon having far more influence on the femoral rather than acetabular offset might be why the latter is often used only as a confounding variable in multivariate models. To our knowledge, however, no published literature addresses whether or not femoral offset should instead be adjusted based on acetabular offset as opposed to vice versa.

Future proposals

To address the underrepresentation of acetabular offset in THA, there remains a need for additional research to better support surgical decision-making processes. A major obstacle to achieving this goal is finding a satisfactory solution for outlining parameter change boundaries between patients of varying pelvis geometry.

Regarding the aforementioned accuracy of measurement as it relates to offset, we propose that only 3D modeling with CT scan be used as opposed to radiographs due to its inaccuracies. The CT scan alternative, for example with bi-plane X-rays, is also preferable to assess offset because 2D radiograph templating cannot appreciate the rotation of the lower limb (23). This technique has already been shown to be effective: using low-dose CT with 3D measurements in the pre- and postoperative evaluation of THA yields excellent inter- and intra-observer agreement (intraclass correlation coefficient above 0.9) (39). Studies with radiograph measurements should thus be considered in light of their limitations.

On the topic of definition, we suggest that the true floor offset model – defined by the distance between the center of the femoral head and the true floor of the acetabulum – be the gold standard one for research. The acetabular measurement per this definition is repeatable and already dominates the literature, so standardizing it can help improve comparability and understanding of all studies. Alternatively, the true floor definition could be limited to

surgical practice, whereas Pauwels definition could relate only to biomechanical analysis.

As for outlining the best method of measurement accuracy and parameter guidelines, we highlight several possibilities. Determining patient-specific offset goals for anyone undergoing THA still seems logical despite its difficulty in practice. One such study identified target limb length for each patient based on patient perception and severity of the disease, equaling offset to the contralateral limb (42). This allowed surgeons to accurately achieve target offset length to within 5 mm for patients with unilateral hip osteoarthritis with excellent clinical outcomes (42, 43). Even still, this method is limited to comparing the contralateral side pre- and postoperatively to determine a length that should not change and can thus be a basis for another. Theoretically, this can then define another length as reliable within a certain margin. A promising diverse method proposed by Esbjörnsson *et al.* (26) uses a ratio instead of a measurement system. This femoral offset/acetabular offset ratio evaluates its effect on gait as a relative measure and is thus independent of the size of the pelvis. Ratio has been referenced in past studies as well, but it may warrant additional exploration to define the ideal ranges of offset parameters in function (14). Such research should be performed with attention to patient-related factors such as age and comorbidities and implant-related factors ranging from component positioning to head–neck ratio.

The multiple definitions of the change in offset used in the literature may lead to a mismatch in clinical recommendations. We, therefore, recommend using the pre-surgery ipsilateral side as the reference when assessing variation in femoral, acetabular, or global offset due to THA, for three reasons. First, this definition was favored by the majority of studies. Second, this change relates directly to the change in the geometry of the surrounding soft tissues and could be relevant for clinical outcomes such as trochanteric pain. Third, the contralateral side is frequently pathological and may not provide a suitable estimation of the joint geometry before the onset of hip osteoarthritis.

Regardless of which method is ultimately determined as the best approach, optimal functional outcomes will almost certainly result from a complex combination of factors. Clement *et al.* (22) expressed a similar idea, stating that: 'the exact anatomic parameters of the femoral and acetabular components that relate to the optimal outcome of patients undergoing a THA remain to be identified'. In the study of Worlicek *et al.* (43), for instance, the discrepancy of a single parameter such as leg length, femoral offset, or acetabular offset did not differentiate patient pain, but rather a specific combination significantly reduced postoperative pain and improved clinical outcomes. Advanced statistical analysis may someday unveil these ideal relationships of THA. With robot-assisted surgery, which has already shown improved Harris hip score and restoration of global offset compared to manual surgeon control, it is hoped that future planning will be more achievable and reproducible (44) and will help identifying optimal target values for improved surgical outcomes.

This narrative study is inherently limited in its non-systematic scope and therefore does not consider all published material on offsets. Additionally, it includes several studies that report results in only percentages or lengths, which restricts cross-comparison. Findings from this study should therefore be viewed more for their value in exposing gaps in the literature rather than in determining surgical parameters for these offsets.

Conclusion

Throughout the literature, there is general agreement that femoral offset should be slightly increased up to 5 mm and global offset maintained during surgery for improved functional outcomes. However, the literature present multiple discrepancies regarding definition of change in offset. To standardize findings, we recommend using the pre-surgery ipsilateral side as reference for change in offset. Many studies indicate that global offset is a crucial factor that should be restored from THA. There exists less conclusive literature regarding acetabular offset, however, albeit a relevant geometrical parameter. This is likely due to issues related to surgical control, measurement difficulties, uniformity in definition, and anatomical variability. Agreeing on the true floor definition for acetabular offset and exploring promising techniques like those mentioned may be the next steps to ultimately determining patient-specific parameter ranges that optimize functional outcomes. In summary, this study stresses the importance of offsets as a hip parameter consideration and draws specific attention to acetabular offset, the potential importance of which has been largely overlooked to date and warrants further exploration.

ICMJE conflict of interest statement
The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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