The influence of component positioning on total hip replacement biomechanics

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Abstract. Objective: Total hip replacement is a commonly performed procedure worldwide for the treatment of hip osteoarthritis and femoral neck fractures offering good overall results. Nevertheless, complications such as abnormal gait and aseptic loosening can occur, leading to pain and functional impairment requiring a complex treatment. Restoration of normal hip biomechanics is an important factor in preventions of these complications. The objective of the study was to compare static biomechanics in total hip replacement to the ones obtained preoperatively and in the contralateral hip. Material and methods: We have retrospectively reviewed 100 cases for calculation of abductor lever arm, body weight lever arm, joint reaction force, acetabular cup inclination, leg length discrepancy, femoral neck angle and femoral offset. Results: The body weight lever arm was longer in the preoperative group compared to postoperative group (11.05 cm vs. 10.66 cm) (p=0.01). The same result was obtained when comparing preoperative to contralateral measurements (11.05 cm vs. 10.6) (p=0.019). When comparing the postoperative hip to contralateral hip, the only statistically significant difference was in case of abductor lever arm, which was longer in case of contralateral hip (6.47 cm vs. 6.07 cm) (p=0.03). Conclusions: Postoperative and contralateral hips have a decreased body weight lever arm compared to preoperative hip. Postoperative hip presents a decreased abductor lever arm compared to contralateral hip. Nevertheless, the joint reaction forces within the preoperative, postoperative and contralateral hips are not statistically significant different.

Key Words: total hip replacement, biomechanics, joint reaction force, lever arm, Trendelenburg gait.

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Introduction

Hip osteoarthritis is a degenerative joint disease consisting in loss of articular cartilage, osteophyte formation, subchondral cysts, muscle weakness, synovitis and periarticular ligamentous laxity (Lespasio et al 2018). Hip osteoarthritis leads to pain generally located in the groin, physical impairment and loss of independence (Lespasio et al 2018). The etiology can be either primary, where the cause is idiopathic, or secondary, following trauma or inflammation (Lespasio et al 2018, Badulescu et al 2018, Badulescu et al 2017). The prevalence of symptomatic hip osteoarthritis is 18.5% for men and 28.6% for women (Lespasio et al 2018). Treatment of hip osteoarthritis is represented by non-pharmacological methods (e.g. physical therapy, weight reduction, orthotics etc.), pharmacological methods (e.g. acetaminophen, nonsteroidal anti-inflammatory drugs, intraarticular injections etc.) and surgical methods which are used when other methods have failed and include hip arthroscopy, hip resurfacing and total hip arthroplasty (Lespasio et al 2018, Sirbu et al 2017).

Total hip replacement is a commonly performed procedure worldwide for the treatment of hip osteoarthritis. A total hip replacement is composed of an acetabular metal component, a polyethylene insert, a femoral metal stem and a femoral head, which can be either metallic or ceramic (Figure 1,2) (Sariali et al 2008, Niculescu et al 2015, Niculescu et al 2014). Total hip replacement is intended to reduce pain, as well as to restore the normal anatomy and kinematics of the hip joint (Sariali et al 2008).

Although it offers a good result overall, multiple complications can occur, including bleeding, vascular injury, neural deficit, wound complications, thromboembolic disease, dislocation/instability, periprosthetic fracture, abductor muscle disruption, deep periprosthetic joint infection, heterotopic ossification, bearing surface wear, osteolysis, groin pain, pseudotumors, metallosis, aseptic loosening, cup-liner dissociation, implant fracture or death (Niculescu et al 2015, Healy et al 2016).

The most frequent postoperative complication is represented by aseptic loosening, resulting in pain and functional impairment of the hip. The etiology of aseptic loosening is multifactorial

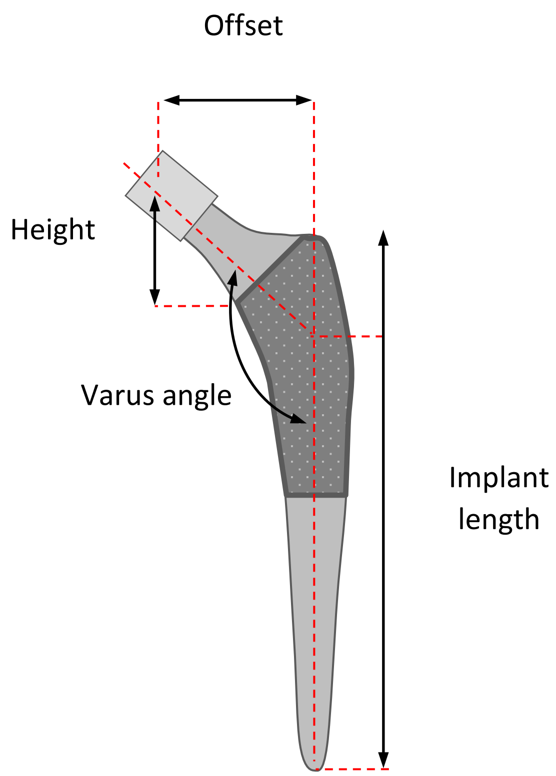

Figure 1. Structure of femoral component

including an impaired initial fixation, component malpositioning, particle-induced osteolysis or increased forces acting on the implant components (Apostu et al 2018, Herle et al 2010). This complication is treated by complex surgical interventions called revision surgeries, which usually result in an inferior functional score compared to primary hip revisions (Apostu et al 2018).
Another frequent postoperative complication is represented by the abnormal gait, also called Trendelenburg gait, where the pelvis tilts down on the opposite site during walking. This is caused by an insufficient abductor force, mostly represented by gluteus medius muscle. The incidence of abnormal gait is higher in hip replacements performed on a lateral approach due to a direct injury of the gluteus medius muscle. Apart from the muscle injury, the abnormal gait can be due to a decreased abductor lever arm which can be caused by an insufficient medialization of the acetabular component. Trendelenburg gait leads to functional impairment and in some cases can be treated with intensive physiotherapy.
In case of a normal hip, during unipodal stance, the body weight lever arm is almost three times the length of the abductor muscles lever arm represented by gluteus muscles, tensor fascia lata, piriformis and obturator internus muscles (Houcke et al 2017, Byrne et al 2010). Therefore, the abductor force needed is three times the force of the body weight in order to keep the pelvis leveled during walking.
The joint reaction force is generated at the hip joint level, and is determined by body weight force, body weight lever arm, abductor force and abductor lever arm. The joint reaction force is increased by overweight (obesity) and extended body weight lever arm. On the other hand, the joint reaction force is decreased by an increased abductor muscle force and increased abductor lever arm. When the joint reaction force is increased, it can lead to both Trendelenburg gait and aseptic loosening (Electricwala et al 2016).
The joint reaction force can be decreased by medialization of acetabular component, increase in femoral offset, use of a cane on the contralateral hand or by shifting the body weight over the affected hip.
Apart from the static biomechanics of the hip, dynamic biomechanics during physical activities has also been studied (Houcke et al 2017). It was first introduced in 1966 by Rydell and improved by Bergmann in 1988 with the help of instrumented hip replacements (Houcke et al 2017). Dynamic biomechanical studies showed that the average hip joint loading was 238% of body weight during walking, 251% of body weight during climbing upstairs and 260% of body weight during going downstairs (Houcke et al 2017).
The aim of the study is to compare the abductor lever arm, body weight lever arm and joint reaction force values at the site of the total hip replacement to the ones obtained preoperatively and in the contralateral hip. The results of these measurements identify the influence of component in case of uncemented hip replacements on joint reaction force, which can lead to late complications in case of high values.

Materials and Methods

We have retrospectively reviewed 100 patients diagnosed with hip osteoarthritis which underwent total hip replacement at our

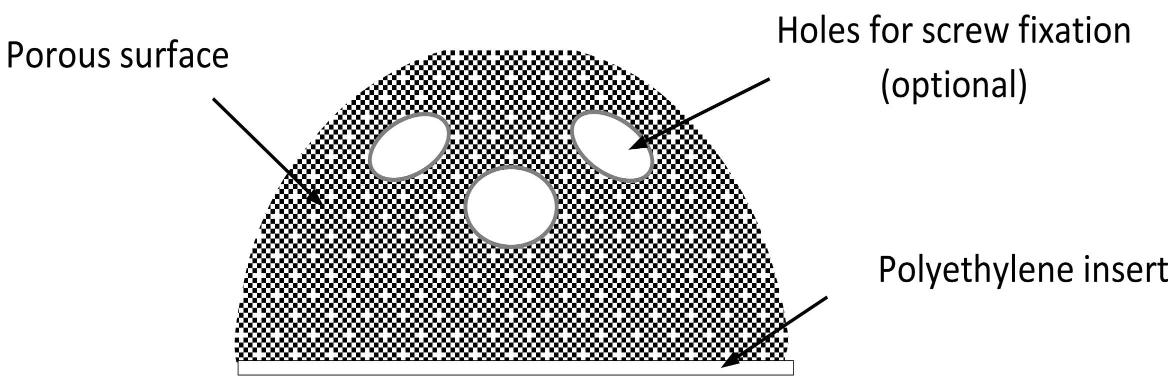

Figure 2. Cementless acetabular component structure

institution during 2017. The inclusion criteria were the presence of postoperative anteroposterior (AP) view of pelvis or both preoperative and postoperative hip AP views. Exclusion criteria were represented by malrotated x-rays (lesser trochanter overexposed or less exposed, as well as unequal obturator foramina), revision surgeries, or hip x-rays on which the horizontal reference line was impossible to determine.

X-ray measurements and calculations. The measurements of length and angles were performed using the same specialized software (RadiAnt DICOM Viewer). The preoperative hip, postoperative hip and contralateral hip were analyzed following the same steps.

Step 1: determination of the horizontal reference line by joining the two teardrop structures (Figure 3 a);

Step 2: determination of the acetabular line formed between the lateral margin of the acetabular roof and inferior part of teardrop structure (Figure 3 b);

Step 3: calculation of acetabular cup inclination formed by the acetabular line and the horizontal reference line (Figure 3 c);

Step 4: determination of the leg length discrepancy using the horizontal reference line and the base of the lesser trochanter (Figure 3 d,e);

Step 5: placement of a vertical line centered on the pubis symphysis (body weight line) (Figure 1 f);

Step 6: determination of the femoral head center of rotation (Figure 3 g);

Step 7: determination of the abductor vector trajectory (Figure 3 h);

Step 8: measurement of the perpendicular line connecting the center of the femoral head to the body weight (BW) line (Figure 3 i);

Step 9: measurement of the perpendicular line connecting the center of the femoral head to the abductor vector trajectory (Figure 3 j);

Step 10 (in case of nonoperated hips): determination of femoral neck angle formed by a line parallel to the femoral diaphysis and a line parallel to the femoral neck (Figure 4 k);

Step 11 (in case of operated hip): calculation of femoral offset from the lateral margin of the ipsilateral teardrop structure to a line parallel to the femoral stem (Figure 4 m).

Based on these calculations, the joint reaction force (JRF) was calculated following the equations: (A x My) + (B x W) = 0 ;

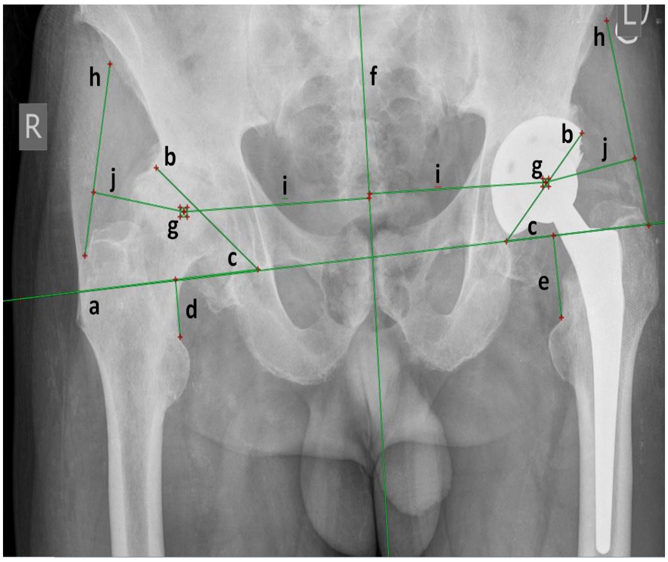

Figure 3. Radiological measurements for steps 1-9

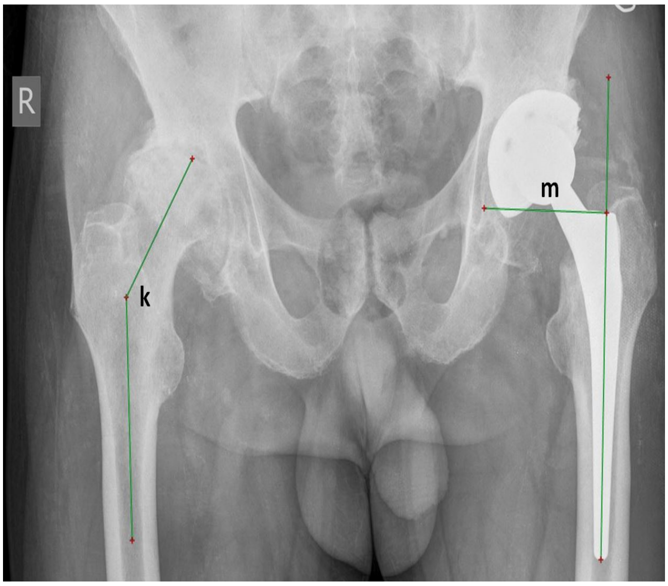

Figure 4. Radiological measurements for steps 10-11

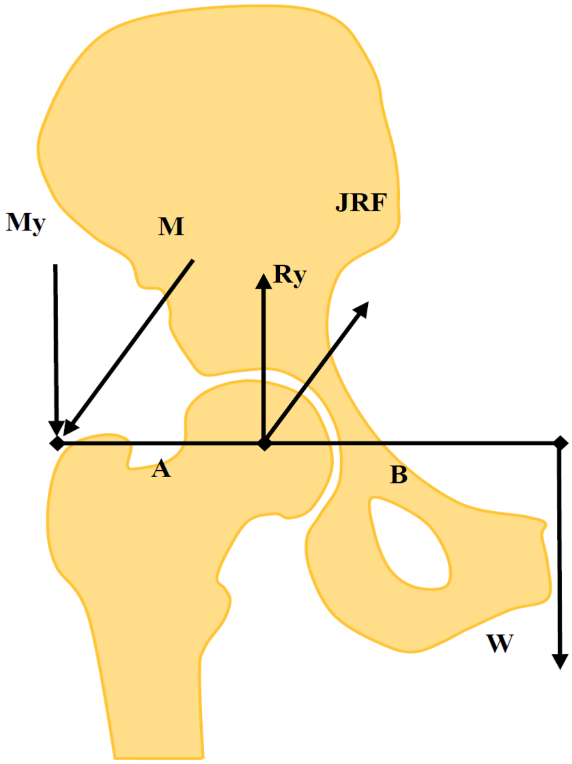

Figure 5. Calculation of hip joint reaction force (JRF)

Ry = My + W and R = Ry / (cos 30°) (Figure 5). The final input equation was JRF = (B/A x W + W) / 0,866.

Coxa vara was diagnosed in case of a femoral neck angle less than 126 degrees, while coxa valga was diagnosed in case of a femoral neck angle more than 139 degrees (Electricwala et al 2016).

Statistical analysis. Statistical analysis was performed using GraphPad Prism 6.0. We calculated means, standard deviations, correlation test and student test for unequal variances. The differences were considered statistically significant if $p<0.05$.

Table 1. Results of preoperative, postoperative and contralateral measurements.

Parameter	Preoperative Mean (± SD)	Postoperative Mean (± SD)	Contralateral Mean (± SD)
Femoral neck angle	127.6 degrees (±12.86) (n=74)	-	128.5 degrees (±8.76) (n=58)
Femoral off-set	-	7.761 cm (±0.96) (n=98)	-
Abductor lever arm	6.190 cm (±1.129) (n=74)	6.071 cm (±0.99) (n=95)[c]	6.472 cm (±1.179) (n=55)[b]
Body weight lever arm	11.05 cm (± 1.032) (n=75)[b,c]	10.67 cm (±0.97) (n=94)[a]	10.66 cm (±0.87) (n=59)[a]
Joint reaction force	3.342 x BW (±0.77) (n=74)	3.32 x BW (±1.25) (n=91)	3.138 x BW (±0.56) (n=55)
Acetabular cup inclination	-	38.66 degrees (±8.015) (n=94)	-
Leg length discrepancy		1.2 cm (±4.21) (n=34)	

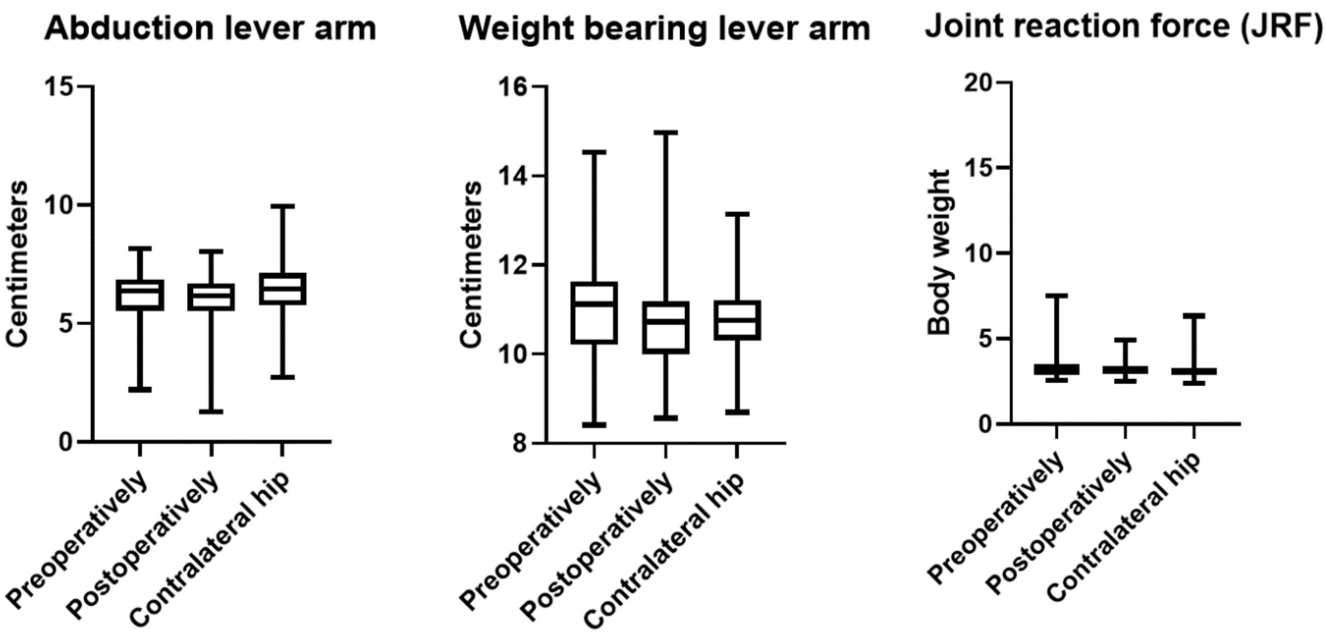

Figure 6. Box-plot chart representing the results of abduction lever arm, weight bearing lever arm and joint reaction force in the preoperative, postoperative and contralateral hip settings.

Results

The patients involved in the study were represented by 49 women and 51 men, 21 cemented hip replacements and 79 uncemented hip replacements, while the average age was 59 years (± 13.56). The preoperative, postoperative and contralateral analysis results are available in Table 1 and Figures 6,7. Preoperative coxa vara was present in 30 cases (30%) and coxa valga in 8 cases (8%). The only statistically significant difference between preoperative and postoperative measurements included the body weight lever arm, which was longer in the preoperative group compared to postoperative group - 11.05 (± 1.032) cm vs. 10.66 (± 0.97) cm (p=0.01). The same statistically significant result was obtained when comparing preoperative to contralateral measurements - 11.05 (± 1.032) cm vs. 10.66 (± 0.87) cm (p=0.019). When comparing the postoperative hip to contralateral hip, the only statistically significant difference was in case of abductor lever arm, which was longer in case of contralateral hip - 6.47 (± 1.179) cm vs. 6.07 (± 0.99) cm (p=0.03).

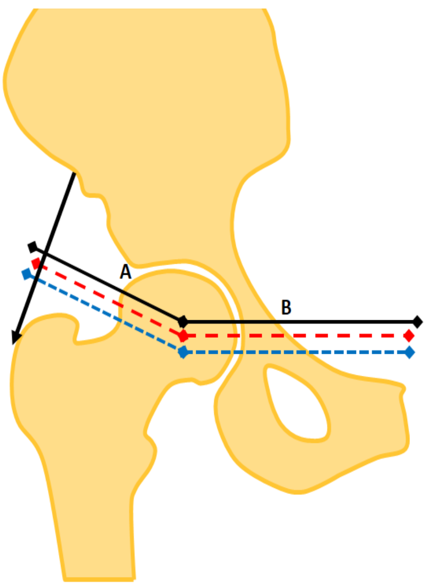

Figure 7. Representation of the average abductor lever (A) and average body weight lever arm (B) preoperatively (black line), postoperatively (red dash line) and contralateral (blue squared dot line).measurements.

Discussions

To our knowledge, this is the first research paper to compare the postoperative abduction lever arm, body weight lever arm and joint reaction force to preoperative and contralateral leg in total hip replacements.

Coxa valga had a lower incidence in our cases, while coxa vara had a higher incidence compared to a previous study (Clohisy et al 2009). The difference is most likely due to different patient inclusion criteria. While our study included all the patients with total knee arthroplasty, the previous research paper focused only on patients with hip dysplasia, which is known to increase the incidence of coxa valga (Clohisy et al 2009).

The preoperative abduction lever arm values found in our study were similar to a study performed by Bjørdal & Bjørgul (2015). The body weight lever arm in preoperative hip replacement also had similar values to a study performed by Rolfe (2006), but the mean joint reaction force was 20% lower in our study. The difference can be explained by a low number of cases in the previous study. We did not find any research paper to compare the preoperative to postoperative body weight lever arm.

Contrary to the results obtained by Bjørdal F et al, the postoperative abduction lever arm was less in our study compared to preoperative values (Bjørdal & Bjørgul 2015). The difference is most likely due to a high offset hip replacement used by the previous authors, while our study included standard offset hip replacements (Bjørdal & Bjørgul 2015). Leg length discrepancy in our study is according to current literature, where a 3-15mm mean discrepancy is described (Rolfe et al 2006, Desai et al 2013). The acetabular cup inclination in our study is similar to current recommendations in the literature, which is between 30 to 50 degrees (Vanrusselt et al 2013). We did not find any study to calculate the body weight lever arm and joint reaction force following total hip replacements.

The total hip replacement had decreased the body weight lever arm to similar values found in the contralateral hip, resulting in a decreased joint reaction force and a lower risk of Trendelenburg gait or aseptic loosening. The overall longer abductor lever arm in case of postoperative hip compared to contralateral hip is due to acetabular cup medicalization and results in a lower abductor force needed to balance the body weight force (Terrier et al 2014). Nevertheless, acetabular cup medialization must avoid potential risk such as excessive loss of the acetabular bone stock and potential proprioceptive-related complications due to an abnormal center of rotation (Terrier et al 2014).

Limitations of the study include lack of preoperative x-ray in some cases. Moreover, as a retrospective study, the clinical outcome of patients such as presence of abnormal gait could not be measured. As we have retrospectively reviewed patients within the year 2017, the risk of aseptic loosening could not be determined. Moreover, we have only analyzed static biomechanics, without any dynamic biomechanics elements to be analyzed in the present study. Another factor that can affect the results and has not been taken into account during our study is the acetabular component anteversion or retroversion, as well as femoral component rotation.

Conclusions

Postoperative and contralateral hips have a decreased body weight lever arm compared to preoperative hip. Postoperative hip presents a decreased abductor lever arm compared to contralateral hip. Nevertheless, the joint reaction forces within the preoperative, postoperative and contralateral hips are not statistically significant different.

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