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Biomechanical Analysis of Limping after Total Hip Replacement in Patient with Developmental Dysplasia of the Hip Joint

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Abstract

Aim: Patients with developmental dysplasia of the hip joint sooner or later develop secondary arthritis which turns them to become candidates for total hip arthroplasty surgery. Following surgery, some of them continue to limp, although they experience no pain. We try to offer a biomechanical explanation for persistent limping, and also provide theoretic possibilities to prevent or minimize it.

Methods: In this article, we use our own method of assessment of hip biomechanics on normal and dislocated hip in female patient that has undergone total hip arthroplasty surgery on dislocated side. We used preoperative and postoperative pelvic radiographs on which we assessed biomechanical properties of both hip joints.

Results: After total hip arthroplasty surgery, our patient has pain-free walk, but limping still exists, although smaller. Comparing biomechanical properties between healthy and dislocated and operated hips it can be seen that for biomechanical balance total loading would be about 70% bigger on operated side. Hip abductor muscles cannot give such power because of relative insufficiency, and limping still persists.

Conclusion: This article, in a specific way, explains disadvantages of high positioned hip prosthesis on hip biomechanics and limping. Limping is caused by relative insufficiency of hip abductor muscles because of high position of the great trochanter, and also because of high position of the center of hip prosthesis. Orthopedic surgeon should exercise a caution when informing a patient about the outcome of the surgery, particularly about the limping. Knowledge of hip biomechanics is required in order to prevent false expectations and disappointments of both patient and surgeon.

Keywords: Hip biomechanics; Developmental dysplasia of the hip; Hip arthroplasty; Limping

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Introduction

Normal functioning of the hip joint requires good condition and relation of articular facets, optimal neck-shaft angle (CCD angle), and normal functioning of associated muscles, particularly hip abductors. For adequate functioning, muscles must be healthy and have normal innervations. If not, the muscles don't contract well, and they cannot keep the pelvis in horizontal position, while walking. They are absolutely insufficient. In this paper we will discuss the case when hip abductor muscles are healthy and with good innervations, but nevertheless they cannot keep the pelvis in horizontal position while walking. The reason for that is high placement of the inferior attachment of the hip abductors (the great trochanter). The abductor muscles don't have strength and cannot contract sufficiently; therefore, they are relatively insufficient. It happens in hip joints with Developmental Dysplasia (DDH), and the limping exists, not only because of shortness of the leg, but also because of biomechanical insufficiency.

Pauwels [1] offered explanations (Pauwels theory) for hip biomechanics, based on model of the horizontal scale. Center of the rotation is within the hip joint. On the medial side of the center of rotation is the moment of the force M_1, and on the lateral side is moment of the force M_2. Moment M_1 is expressed as $M_1=k_1 \bullet G$ (G= body weight), while $M_2= k_2 \bullet F$ (F= muscle force of the hip abductors). Medial lever k1 is a distance from the center of the hip to the point of the body weight (G), and lateral lever k_2 is distance from the center of the hip to the tip of great trochanter (in adults they should be in the same horizontal level) (Figures 1-3). Since lever k_1 is about three times longer than lever k_2, the muscle force of abductors (F) should be three times greater than the body weight (G) for biomechanical balance. Hence, while standing on one leg, weight bearing on the hip (force R) is about four times greater than the body weight (R=4G). According to Pauwels, the force R in adults has a 16° inclination angle in the frontal plane (Figure 2, 4).

In situations when horizontal levers k_1 and k_2 are changed (coxa valga, coxa vara, lateral femoral head shift in DDH), we can explain how changes of these levers can act and change hip biomechanics. But, using Pauwels method, we can't explain what happens with hip biomechanics in DDH, because in hip dislocation, not only that the head of the femur moves laterally (causing lengthening of k_1), but it also shifts cranially, and affects hip balance and causes limping. However, Pauwels did not take into consideration cranial shift of the femoral head. For that reason, in our previous publication we have tried to explain hip biomechanics introducing vertical lever k_2 (as presented in previous presentation) [2,3] (Figure 3, 4). On these diagrams, relationship between forces and levers are as follows:

$k_1 \bullet G = k_2 \bullet Fmx$, and $k_1 \bullet G = k_2 \bullet Fm \bullet \sin \alpha$, where the muscle force Fm acting on the vertical lever k_2 (at an angle α).

Following formula [3]:

$$R = \frac{G \bullet k_1}{k_2 \bullet \sin Y},$$

it shows that horizontal lever k1 and vertical lever k_2, if changed, must change the force (R). Lengthening of horizontal lever k_1 (because of the lateral shift of the femoral head) and shortening of vertical lever k_2 (because of the cranial shift of the femoral head) have a negative effect on the biomechanical properties of the dislocated hip joint, resulting in an increase of its loading (force R). Angle γ is an angle of "bending" of force R. Upper attachment of the abductor muscles stay unchanged, but inferior attachment of the abductor muscles (tip of the great trochanter) moved cranially resulting with loosening of abductor muscles.

To achieve biomechanical balance after Total Hip Arthroplasty (THA) on dislocated hip, the following needs to be done:

1. Horizontal lever k_1 should be shortened. It means that acetabular part of the prosthesis must be implanted deeper.

2. Vertical lever k_2 must be elongated. It means that acetabular part of the prosthesis must be implanted lower, as near as possible to the natural acetabulum.

3. Great trochanter also must "go down". It means that we must make larger distance between proximal and distal insertions of the hip abductors.

If, after THA on dislocated hip, we do not change these three parameters, the patient will walk pain-free, but limping will continue to persist, because the reasons for limping will not be removed.

Materials and Methods

A 56-year-old female patient has undergone THA surgery, because of secondary arthritis on her left, Dislocated Hip (DDH). The patient was limping her whole life (pain-free limping), and few years before surgery, it became painful. On preoperative X-ray image of the pelvis, the right hip was normal and the left was dislocated, with strong arthritic changes. The head of the left femur had placement in the neoacetabulum, and it was positioned superolaterally on the iliac bone. Natural acetabulum was completely destroyed (Figure 5). The position of the femoral head in the neoacetabulum was very deep. Hence, the acetabular part of prosthesis was implanted in the neoacetabulum, and femoral part of the prosthesis was with stronger valgus and longer neck (Figure 6). On the postoperative radiograph of the pelvis, the acetabular part of hip prosthesis was in good position in neoacetabulum, and great trochanter was lowered with femoral part of the prosthesis. On that radiograph, we graphically presented hip biomechanics on right (normal) hip, and calculated force value to be R=3.8 G (Figure 6). In the same way, we graphically presented biomechanical situation on the left (dislocated and operated) hip (Figure 7) and calculated force value on that side to be R'=6.5 G.

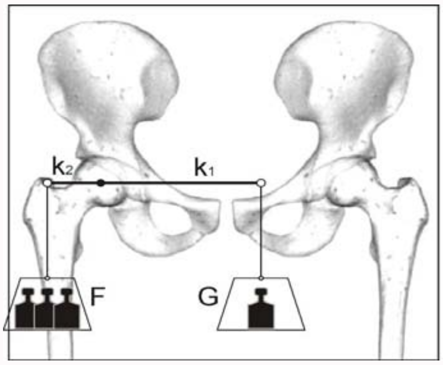

Figure 1: Pauwels scheme of the hip biomechanics. $M_1=M_2$. $k_1 \bullet G = k_2 \bullet F$.

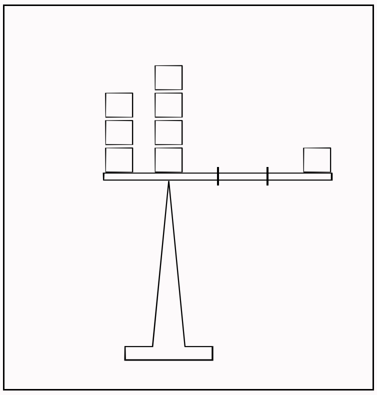

Figure 2: According to Pauwels, total weight bearing of the hip (force R) is about 4G.

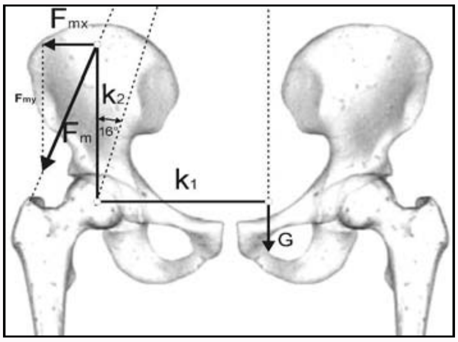

Figure 3: New scheme displaying biomechanical properties of the hip joint, by using vertical lever k_2. $k_1 \bullet G = k_2 \bullet Fmx$, and $k_1 \bullet G = k_2 \bullet Fm \bullet \sin \alpha$.

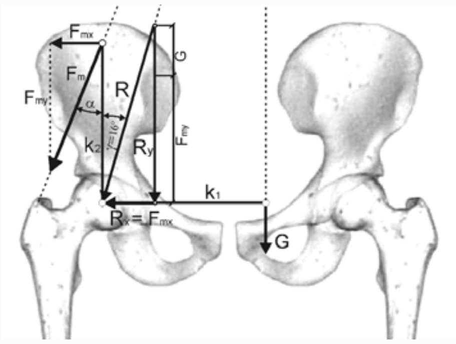

Figure 4: Force R (total weight bearing of the hip) has 16° inclination angles in the frontal plane. Rx=Fmx, and Ry=Fmy+G.

Figure 5: Preoperative radiograph of the pelvis. Right hip is normal, left hip is dislocated, with neoacetabulum present.

Results

From the formula $k_1 \bullet G = k_2 \bullet Fmx$, we found value of Fmx, and determined a value and direction of muscle force Fm, acting on the vertical lever k_2 at an angle of 22° (angle α). It means that $k_1 \bullet G = k_2 \bullet Fm \bullet \sin \alpha$. We graphically presented total loading of the normal right hip (force R) to be 3.8 G (R=3.8 G), (Figure 6, 8). Force R has inclination of 16° in the frontal plane (γ=16°). Component of the force R along the X axis, Rx, is the same as component of the Fmx; Rx=Fmx. Component of the force R along the y axis, Ry, is the same as component Fmy + G; (Ry=Fmy+G). Length of the horizontal lever k1 and the vertical lever k_2 is nearly the same.

Using formula

$$R = \frac{k_1 \bullet G}{k_2 \bullet \sin Y}$$

we also made a mathematical account of force R (total loading of the normal hip) and we found the same values for the force R. Graphically and mathematically we found that total loading of the normal right hip in our patient (force R) is 3.8 G (R=3.8 G). Relation $k_1 : k_2 = 1.06$.

We made the same graphical and mathematical construct of the left (operated) hip in our patient. Results of the graphical demonstration of the biomechanical balance on dislocated left hip after surgery and mathematical account show that in order to obtain the balance, total loading of the hip should be 6.5 G (R'=6.5 G). An angle γ' of the force R' is 27° (γ'=27°). Distance between both attachments of the abductor muscles are smaller (great trochanter is still in high position). Abductor muscles are relatively insufficient and they cannot give such power for hip balance and the balance does not exist, it is only theoretical (Figure 9).

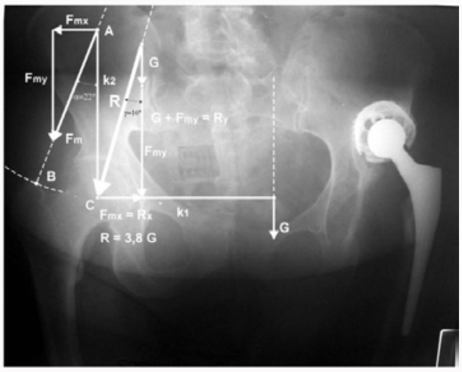

Figure 6: Postoperative radiograph of the pelvis. Right hip with normal biomechanics in balance, R=3.8 G. On the left (dislocated) hip, acetabular component of hip prosthesis is implanted in the neoacetabulum. Femoral part of the prosthesis pulled the femur (and great trochanter) distally. Stem is in valgus, long neck.

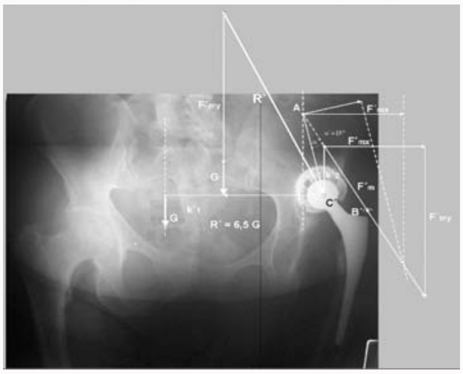

Figure 7: Postoperative radiograph of the pelvis. Left hip with graphical description of hip biomechanics. To achieve biomechanical balance, total loading of the hip (force R') should be 6.5 G, but abductor muscles can't give such power, and balance is theoretical. That is the reason for limping.

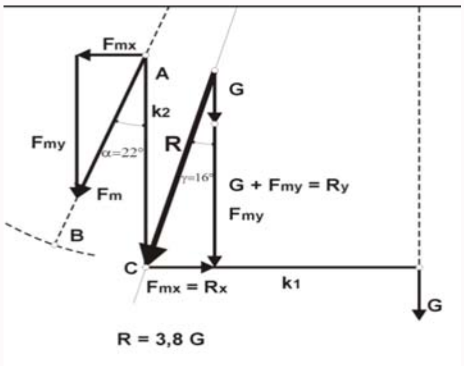

Figure 8: Graphical demonstration of the biomechanical forces and balance in normal right hip in adult (from the Figure 6).

Discussion

In patients with DDH femoral head shifts cranially and laterally because of acetabular deficiencies anterolaterally and superiorly. Dysplastic femurs have increased anteversion, short necks and smaller canals. Musculature around dysplastic hips is shortened, including adductors, and hip abductors are inefficient. Usually, we

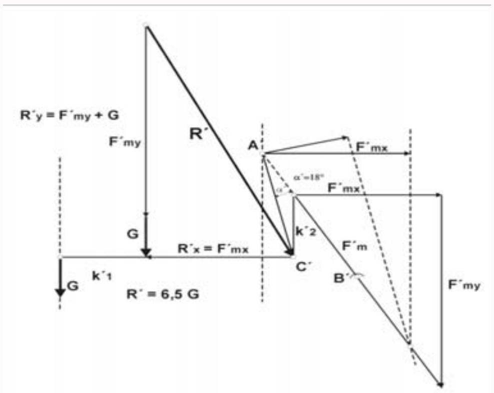

Figure 9: Graphical demonstration of the biomechanical forces and balance in dislocated left hip after surgery (taken from Figure 7). Force R' has inclination angle (angle γ') of 27°. Relation k'_1: k'_2=2.8.
Comparing force R on normal right hip and force R' on dislocated and operated left hip, it is clear that force R' is bigger than force R for around 70%, (R'>R for 70%). To provide balance in this situation abductor muscles appear insufficient, and hip balance is only theoretical; therefore, limping persists.

speak about three types of hip dislocation: Dysplasia, subluxation and luxation. In surgical practice, two classifications are used: Crowe's classification scheme and Hartofilakidis' classification scheme [4,5]. Crowe classification uses a percentage of acetabular covering of the femoral head and differentiates 4 types of dislocation. Hartofilakidis classification has 3 types:

- Type I acetabulum is shallow but femoral head is still located in it;

- Type II low dislocation, femoral head is shifted to the false acetabulum (neoacetabulum), but inferior part of femoral head is still in contact with true (natural) acetabulum.

- Type III high (total) dislocation, femoral head has no contact with true (natural) or false acetabulum.

Many surgeons find this classification to be more practical in guiding surgical treatment [5]. We are not sure that our patient can be classified in one of these 3 types, because she has no natural acetabulum. Neoacetabulum was not in any contact with the natural acetabulum, and was pretty deep (Figure 5). Femoral head was well positioned in the neoacetabulum, and secondary arthritis existed. It seemed that this neoacetabulum was a good place to implant acetabular augmentation and we expected a good mechanical stability of the implant. Other option was to implant acetabular component in the place of natural acetabulum, but such acetabulum did not exist, and it would be a problem how to fix the acetabular augmentation. Therefore, we decided to implant acetabular augmentation in the neoacetabulum. Another reason why we decided to implant acetabular augmentation in the neoacetabulum was that it would necessitate a big femoral reconstruction (resection of the femur in subtrochanteric region). This seemed a great surgery risk so we were prepared to accept postoperative result; the free of pain but still limping patient. The limping was predicted because horizontal lever k'_1 was longer, as was before surgery, and the vertical lever k'_2 was shorter, as was before surgery. Tip of the great trochanter was still too high, and abductor muscles were inefficient. To achieve balance in operated hip, the abductor muscles must be much stronger than muscles on the normal hip, because of total loading on the operated hip. To reach biomechanical balance, the loading would need to be about 70% bigger than the loading of the normal hip. Abductor muscles don't have such power to balance the dislocated hip.

Delp et al. [6,7] also found that superolateral placement of the joint center in hip arthroplasty affects the abductor muscles and decreases the moment arms of the abductors on average for 28%. We think that it happens for more than 28%.

When analyzing hip balance in our patient after surgery, three things were important to notice:

1. Lateral shift of the center of the hip in comparison with normal hip (longer horizontal lever k'_1),

2. Cranial shift of the center of the hip in comparison with normal hip (shorter vertical lever k'_2), and

3. Higher position of the great trochanter in comparison with normal hip.

In order to restore the balance in operated hip the following had to be done:

Ad. 1. The horizontal lever k'_1 must be shorter. This is possible when the acetabulum is implanted in place of natural acetabulum. Since such acetabulum did not exist in our patient, mechanical stability would have been problematic. Neoacetabulum was positioned higher, which meant more laterally and biomechanically it presented a disadvantage.

Ad. 2. The vertical lever k'_2 must be longer. In cases when natural acetabulum exists it can be done, but the problem is how to pull a proximal femur distally to make possible reposition "ball in socket". In high dislocations subtrochanteric resection of femur is necessary. Such surgical procedures go with greater risk and higher rates of failure and revision [5].

Ad. 3. The great trochanter must be moved more distally, to help the abductor muscles to get more power. This depends on the degree of hip dislocation and of the cranial shift. In dysplastic and subluxated hips, it is possible to move great trochanter distally (together with the whole femur) after releasing soft tissues and with implanting stem prosthesis with bigger CCD angle (valgus), and longer neck. But bigger valgus of the prosthesis stem decreases the angle of the abductor muscles (angle α), which is biomechanical disadvantage. Therefore, for the hip biomechanics, it is better to implant femoral stems with greater offset. It means that the stem of the prosthesis for dislocated hips must be of a particular design; valgus stem, long neck and greater offset (all components together). Great trochanter can be osteotomized and transpositioned distally, but Anwar et al. described 29% of nonunions of the greater trochanter, as well as increased frequency of Trendelenburg gate [8].

Subtrochanteric resection of the femur and transposition of the great trochanter significantly complicates operation procedure increasing the operative risk, despite recommendations by several authors [9,10].

Conclusion

Total hip arthroplasty in patients with developmental dysplasia of the hip requires good surgery techniques, great experience and also the knowledge of hip biomechanics. The patient, before surgery, must be well informed of the possible outcome of the surgery, particularly about the limping, to prevent false expectations and disappointments. The surgeon should always be thinking of the following: 1. How to make horizontal lever k'_1 shorter? 2. How to make vertical lever k'_2 longer? 3. How to move great trochanter more distally? and 4. If possible, use the stem of prosthesis with big valgus and long neck and also with a great offset. In this case we decided to implant hip prosthesis (classical one, which we had) in neoacetabulum, because the surgery risk and possible complications for us were unacceptable. Our patient was well informed and prepared for limping (smaller than earlier), but without pain, and she was ultimately satisfied.

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