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Influence of a high hip center on abductor muscle function

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Abstract In 20 anatomic specimens with an acetabular defect (type Paprosky 3b), an acetabular component was implanted in the position of a high hip center. The vertical migration of the hip center ranged between 13 and 35 mm. It was accompanied by a lateralization and ventral migration of between 5 and 25 mm. The influence on the different abductor muscles was calculated through computer model comparing muscle force and muscle length before and after implantation of a high hip center. The increase in length of the gluteus maximus muscle and the posterior part of the gluteus minimus muscle ranged between 1% and 6%, while all other evaluated abductor muscles were shortened from 3% to 16%. The effect of the simultaneous changes of the lever arms was an increase in necessary muscle strength for pelvic stabilization from 140% to 250% compared with the original estimated strength prior to implantation. This may lead to insufficiency of the abductor muscles after placement of a high hip center. On the basis of these findings, we do not recommend the implantation of an acetabular component in the position of a high hip center.

Introduction

During the past few decades, the implantation rate of a total hip prosthesis has significantly increased. This development has led to a broadening in the spectrum of indication being treated and a shift in patient's age downwards [9]. In consequence, due to the limited durability of materials, particularly the polyethylene components [10], aseptic loosening of a total hip prosthesis has become a problem encountered more frequently, especially for the acetabular component [2].

Kavanagh et al. showed an intraoperative manifest loosening of 25% during revision surgery of cemented acetabular components with an average lifetime of 4.5 years [14]. Other authors estimated a 50% incidence of radiographic loosening or 33% symptomatic loosening in cemented acetabular components [4].

With repeated component loosening, bone defects increase until further fixation of a prosthesis becomes impossible. Formerly, the only option in severely affected hips was removal of all components and performance of a Girdlestone [7] procedure. Nowadays, reconstructive measures in cases of extreme osteolysis have increased along with improved prosthesis shapes and surgical techniques.

The high hip center is one possibility several authors [1, 13, 15, 16, 17] favor as a suitable procedure in hip alloarthroplasties with severe bone loss, a situation particularly met in revision surgery. Also, treatment of severe congenital hip dysplasia or dislocation as well as large degenerative and infectious affection of the hip joint have been considered indications for a prosthesis placed further proximal in the iliac bone instead of in the anatomic position.

The purpose of this study was to answer the following questions: (1) How does a high hip center alter the relation between the acetabular cup and the pelvis? (2) How does it change the lever arms? (3) What effect occurs on muscle power and muscle length?

Materials and methods

First, an artificial bone defect similar to those caused by aseptic loosening of the acetabular component with cranial migration or dislocation was created in 20 human specimens. Then an acetabular component was implanted in the position of a high hip center. All specimens were standardized by performing the same defect (type 3b according to Paprosky). For documentation of migration of the center of rotation, all specimens were surveyed before and after the acetabular component was implanted.

After dissecting the abdominal muscles, the lumbar spine was cut at the fourth lumbar vertebra in order to disconnect the pelvis from the trunk. Then the hip joint was exposed by preparation of the femoral neck. The bony defect was performed by deepening the acetabulum in the craniomedial direction, thus creating a large defect in the proximal acetabular rim also affecting the anterior and posterior column, as well as a medial cavitation, both of which are common in aseptic loosening of a total hip endoprosthesis with osteolysis. Next, an acetabular component was im-

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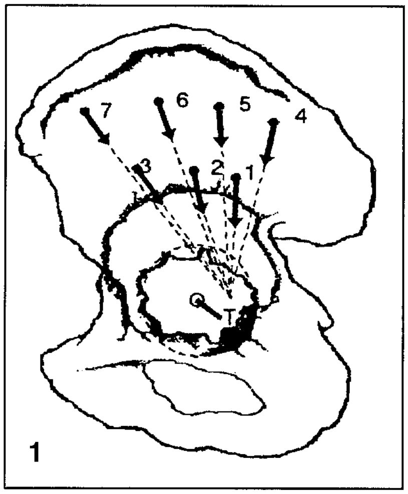

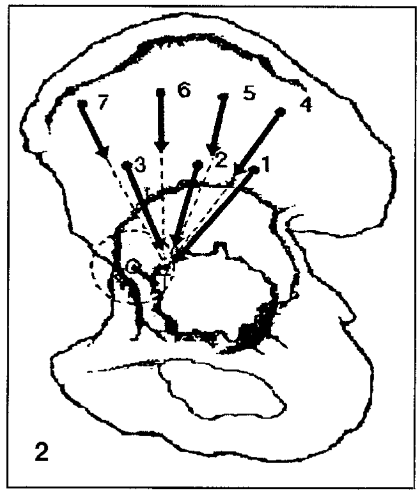

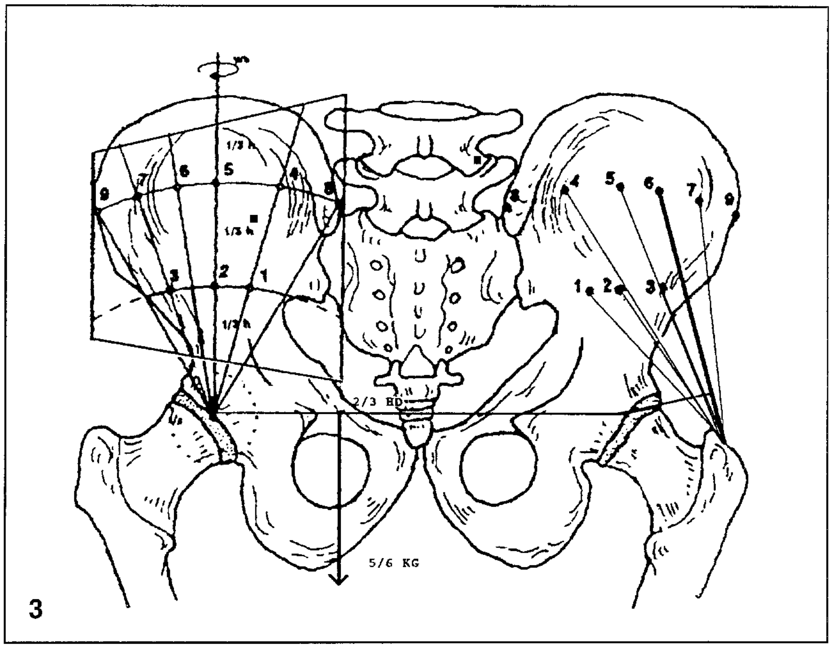

Fig. 1 Muscle force calculation for original anatomic hip center; *T* great trochanter

Fig. 2 Muscle force calculation for high hip center; *T* great trochanter

Fig. 3 Anteroposterior (AP-) projection of the muscle vectors which measured for the calculations; *HD* horizontal hip center distance, *KG* body weight

planted in the position of a high hip center just below the anterior inferior iliac spine into a shallow mold shaped into the corpus of the iliac bone. The created mold was bordered medially by the cortex of the iliac bone and cranially by the spongious anterior inferior iliac spine. The dorsal wall as well was provided by spongious iliac bone.

The acetabular component used was a 36 mm polyethylene cup with a height of 21 mm. The cup was inserted with 12° anteversion and 45° inclination.

The assessment of muscular conditions was performed by using a model primarily invented for gait analysis in patients with affected hip joints. This software is based on a semi-dynamic method which calculates the data of three different phases of ground contact. These three phases are defined by the angle of the femur in relation to the vertical plane (+15°: begin; 0°: middle; –15°: end) of one-leg stance.

Pelvic tilt in the sagittal plane was considered +5° in all three phases. Lateral tilt of the pelvis was 0°, 5° and 10° and horizontal rotation was –5°, 0° and +5° for beginning, middle and end phases. Since all specimens were a pelvis with no femur and cut in half, some standard data had to be used for calculations. Femur length was set at 350 mm in all specimens and femur antetorsion at 12°.

In order to estimate the consequences of a high hip center on abductor muscle force and length, each specimen was assessed in its original condition (Fig. 1) and after insertion of the acetabular component, including migration of the center of rotation in all three planes (Fig. 2).

The following muscles were measured (Fig. 3): gluteus minimus, posterior section; gluteus minimus, intermediate section; gluteus minimus, anterior section; gluteus medius, posterior section; gluteus medius, intermediate section; gluteus medius, anterior section A; gluteus medius, anterior section B; tensor fasciae latae.

The following aspects were considered in the assessment of the original conditions: diameter of the original bony acetabulum; ileum height = distance from upper acetabular rim to highest point of the iliac crest; horizontal distance of original centers of rotation.

In order to assess the necessary angles, all specimens were photographed in a standardized format using a special telephoto lens from 1.5 m distance. The specimen was put into physiologic position. Photos of each specimen were taken cranially as well as laterodorsally to aid measurement of the maximum distances of the iliac wing. The pictures were digitized, and the following angles were assessed: angle of iliac wing to sagittal plane = angle between sagittal plane and line drawn from anterior superior spine to posterior superior spine on cranial photograph; anterior pelvic angle = angle between vertical plane and line drawn from center of rotation and anterior superior spine on laterodorsal photograph; posterior pelvic angle = similar to above but line drawn to posterior superior spine; pelvic tilt = angle between horizontal plane and line drawn through both superior spines on laterodorsal photograph.

Evaluation of physical moment

This is defined as the product of the distance between the vector of the ground reaction force from the hip's rotation center and the amount of this force acting on the hip joint frontally. Any changes in the centers of rotation cause shifts in the pelvic geometrics, especially through lateralization. Therefore, the physical moment was calculated for each specimen prior to and after insertion of a high hip center according to the following formula:

$$M = \frac{2}{3} HD \times \left(750 \times \frac{5}{6} \right) \times 0.67 \, (\mathrm{Nm})$$

where HD = horizontal distance between centers of rotation (m).

At first, the horizontal distance between the centers of rotation was measured. Since all specimens had been cut in half, the horizontal distance between the centers of rotation and the sagittal plane was doubled. In order to calculate leverage in the one-leg stance, two-thirds of this distance were used in the formula above. Body weight was estimated at 75 kg and five-sixths was used in calculations, taking into account the one-leg stance and subtracting the weight of the ipsilateral leg. Factor 0.67 at the end of the formula represents the percentage of mean physical moment during the entire one-leg stance in gait phase. This factor is an empiric number which coincides in this case with two-thirds and is added to the original formula based on calculations by Tetzlaff [18].

The same formula was used for calculation in the high hip center, taking only lateral migration into consideration because of its crucial effect on physical moment.

In order to achieve comparability for further calculations, all other parameters mentioned above remained the same. Only the migration of centers of rotation, and therefore, the changed physical moments were varied. For evaluation of muscle force and strength, migration in all three planes was measured and used in further calculations.

Results

Migration of center of rotation

Data for vertical migration vary from 13 to 35 mm with an average of 25 mm (Table 1). In all specimens a mean lateralization of 17 mm in centers of rotation occurred. Ventral migration ranged from 5 to 25 mm.

Calculation of physical moment

In the anatomic position there was a variation between 39.08 and 46.89 Nm (Table 2). These values overlapped with the findings in high hip centers, which ranged between 44.29 and 54.71 Nm. This emphasizes the great interindividual range of possible forces in the human pelvis. A considerable rise of physical moment due to lateral migration of the centers of rotation is evident. Individual ranges up to 10 Nm or more are possible, showing the relation between lateralization and rise in physical moment. Whereas specimen no. 2 with a lateral migration of 30 mm also shows the greatest rise in physical moment, the latter is less affected in those specimens with only 10 mm of lateralization. For abductor muscles, this means an increased load and force necessary to stabilize the pelvis.

Table 1 Migration of center of rotation data

Specimen no.	Vertical (mm)	Sagittal (mm)	Lateral (mm)
1	20	+25	15
2	35	+25	30
3	25	+23	25
4	30	+20	15
5	20	+20	25
6	25	+15	15
7	35	+25	15
8	28	+15	20
9	25	+20	20
10	30	+18	25
11	20	+10	10
12	24	+5	15
13	24	+5	10
14	15	+10	15
15	20	+10	10
16	30	+7	20
17	13	+10	20
18	27	+5	10
19	30	+5	16
20	27	+5	10
Average	25	+14	17

Table 2 Calculation of physical moment

Specimen no.	Physical moment		Difference (Nm)
	Old (Nm)	New (Nm)	
1	47	49	+2
2	36	52	+16
3	42	55	+13
4	47	55	+8
5	39	52	+13
6	44	52	+8
7	39	47	+8
8	43	55	+12
9	39	49	+10
10	42	55	+13
11	42	47	+5
12	44	52	+8
13	44	49	+5
14	44	52	+8
15	42	47	+5
16	42	52	+10
17	44	55	+11
18	39	44	+5
19	42	50	+8
20	39	44	+5
Average	42	51	+9

Calculation of muscular conditions

Comparing data prior and after insertion of a high hip center, a rise in load is manifest for all sections of m. gluteus minimus and m. gluteus medius. The necessary muscle power is highest at the beginning of the stance phase and gradually falls towards the end.

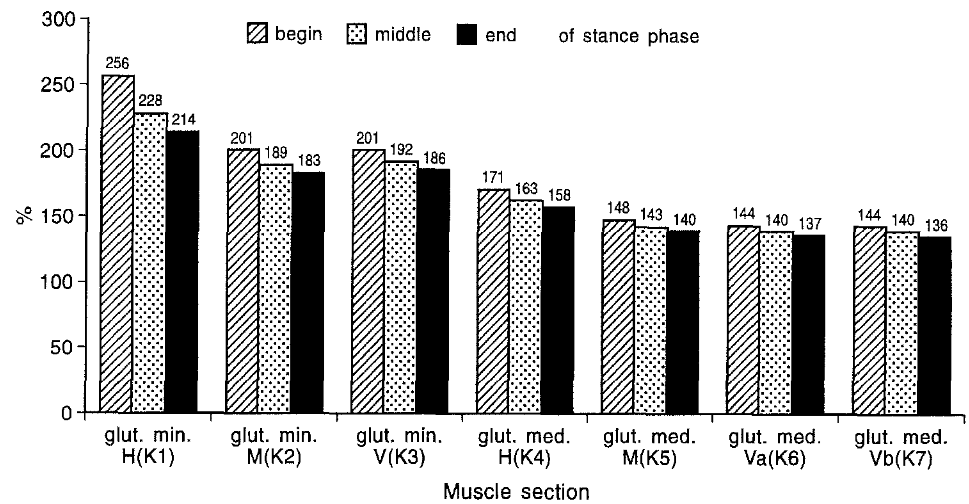

Fig. 4 Average increase in muscle force for high hip center (percentage of original values)

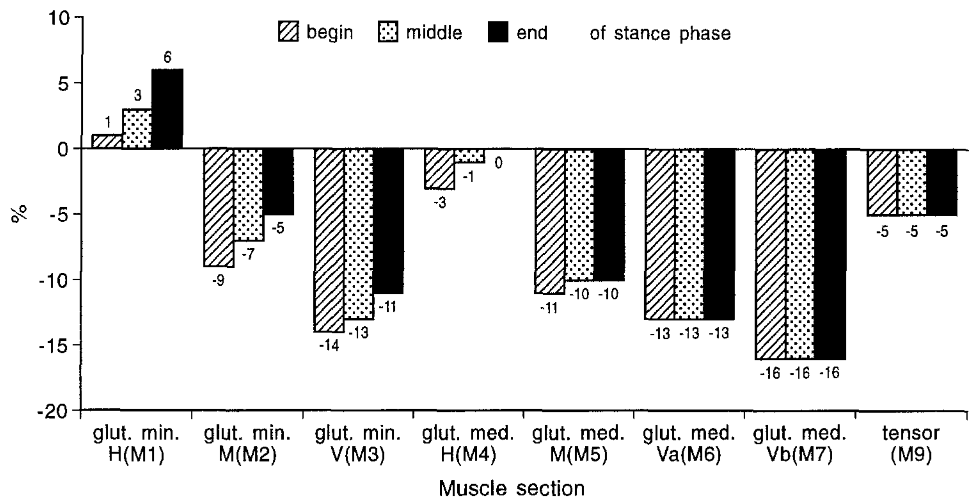

Fig. 5 Average change in muscle length for high hip center (percentage of original values)

This is based on the change in levers for abductor muscles. Due to lateralization of the center of rotation, levers for those muscles become smaller leading to a higher physical moment.

The most affected muscle is gluteus minimus, especially the posterior part K1 which has to cope with an increase in necessary muscle force of 250% compared with its original load. Both posterior sections, though less affected at 180% and 200%, still have to increase their necessary muscular force by a factor of two (Fig. 4).

In m. gluteus medius, it is also the posterior part that is most affected, with an increase of 160%, while the other sections increased 140% over their original constitution.

The study showed that abductor muscles have to work under highly unsuitable lever conditions, making physiologic working impossible. The center of rotation is shifted too close to the effective muscular origins, resulting in a short lever arm which makes abductor working conditions impossible. This especially affects m. tensor fasciae latae, which loses its abductor function according to these calculations.

Comparing muscular length before and after insertion of a high hip center shows that only the posterior part of m. gluteus minimus M1 is increased, whereas all other muscles experience a decrease (Fig. 5). The decrease in muscle length is highest in the anterior parts of m. gluteus minimus and m. gluteus medius, with up to 15% in M7. The intermediate section of m. gluteus medius is also shortened by 15%, whereas m. tensor fasciae latae is affected by a 5% loss.

Discussion

Altering the position of the hip joint center always changes the resulting forces. Johnston and Brand [13] showed a significant relation of postoperative limping to the following three factors: (1) sum of moments muscles have to create during gait; (2) length of lever of each muscle; (3) muscle capacity.

In contrast to the study of Russotti and Harris [17], a lateralization of the center of rotation was detected in each specimen after insertion of a high hip center in our study. Ventral migration was also detected in every specimen.

Under otherwise unchanged conditions, a high hip center results in a decrease of muscle length in the abductor muscles. An average of 16 mm was detected in that part of m. gluteus medius located straight above the center of rotation in the frontal plane in a normal hip joint. That section was used in this study as representative for all abductor muscles for comparative purposes. The reason for the increase in length in the study of Russotti is the translocation of the great trochanter with a resulting decrease in distance for the abductor muscles of an average of 30 mm [13]. The decrease in muscle length detected in this study, though, is only one reason for the functional loss of the abductor muscles. Through lateralization, the physical moment is affected in a negative way by changes in lever conditions, especially for the posterior parts of m. gluteus medius and minimus. For these reasons, a muscular insufficiency develops in two ways: First of all via a decreased preload due to a decrease in length, and second by a change in lever conditions.

Some muscles like m. tensor fascia latae move so close to the center of rotation with their effective diameter that the lever force is changed so that physiologic working becomes impossible. This muscle loses its abductor function, as shown in this study. In studies dealing with the effects of Chiari's operation, Delp et al. draw the conclusion that changes in muscle length have a greater influence in decreasing the muscle force than changes in lever conditions [3].

In their comparison between radiographic evaluations and clinical examination, Gore et al. stated that there is a significant correlation between decrease in muscular force and proximal placement of the acetabular component nor equalled by a longer femur shaft [8].

Summarizing the information given, the following conclusions can be drawn: Changes in muscle length, especially reductions, with constant neuronal activity have the greatest influence on muscle force. The geometric changes in the pelvis due to a high hip center cause a great increase in the necessary muscle force in the abductor muscles to keep balance. This is especially the case for m. gluteus minimus and the posterior sections of m. gluteus medius. When interpreting these data, one has to consider that a straight line model of the muscles was used. Since particularly the abductor muscles in the human pelvis are characterized by a broad origin, it has to be assumed that some of the fibers have to work under different conditions. This was taken into account by dividing those muscles into sections in order to minimize any possible bias in the calculations. However, the data can only show a tendency for possible consequences since a large interindividual range has to be considered.

In the clinical setting, the muscular insufficiency might be even greater, because the changes in muscle length are differently distributed along the overall muscle length. Physiologically, a muscle consists of contractile and noncontractile elements, and the latter are much less capable of changes in length, either active or passive. It is therefore likely that changes in the overall muscular length calculated in this study affect the contractile elements to a higher degree than numbers might show.

The possible life time of a total hip prosthesis increases, according to calculations of Johnston and Larson with a decrease in the forces affecting the components. This is achieved by placing the acetabular component as far medially, anteriorly, and inferiorly as possible [12].

Because of these findings, Emerson et al. referred the problem of postoperative dislocation with acetabular bone grafts in their study to similar forces [4]. Though the causes are multiple, the authors agree in this respect with Etienne et al., Fraser and Wroblewski, and others in stating that a different placement of the acetabular components, especially proximal, is a significant risk factor for postoperative dislocation [5, 6].

The data collected in this study support these conclusions because of the muscular insufficiency of the abductor muscles that is likely to develop. With additional problems of adequately fixing the acetabular component [12, 13], a high hip center does not seem to be an appropriate method in total hip prosthesis revision surgery.

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