Computer simulation of periacetabular osteotomy

France Srakar[1], Ales Iglic[2,3], Vane Antolic[1] and Sreco Herman[1]

A simple static three-dimensional mathematical model of an adult hip in one-legged stance was used to evaluate the mechanical situation after periacetabular osteotomy. We found that the hip joint rotation center shifted as a consequence of the osteotomy. This may have considerable effects on the hip joint resultant force and therefore also on the pressure on the femoral head, which could cause the development of arthrosis.

[1]University Clinical Hospital for Orthopedics, Slovenia; [2]Medical Faculty, Institute of Biophysics, and [3]Faculty of Electrical and Computer Engineering, Trzaska 25, 61000 Ljubljana, Slovenia
Correspondence: Dr. France Srakar, University Clinical Hospital for Orthopedics, Zaloska 9, 61000 Ljubljana, Slovenia
Tel +38-61 317 266. Fax +38- 61 316 078
Submitted 91-07-20. Accepted 92-02-16

Acetabular osteotomy permits rotation around the hip joint rotation center, which is believed to coincide with the femoral head center. The operation is often sufficient to compensate for lateral and/or anterior roof insufficiency (Ganz et al. 1988). However, sometimes the acetabular fragment must be rotated around a more proximal or distal axis, which results in medial or lateral displacement of the hip joint rotation center; lateralization of the hip joint rotation center must be avoided because dysplastic hips cause an inherent lateral displacement of that center (Ganz et al. 1988). We report a mathematical simulation of the periacetabular osteotomy.

Methods

We have used a simple static three-dimensional mathematical model of an adult human hip in one-legged stance, as described in detail by Iglic et al. (1990); the main assumptions and characteristics of the model are given here. The model is defined by force and moment equilibrium equations. The piriformis, gluteus medius, gluteus minimus, rectus femoris, and tensor fasciae latae muscles are included in the model. Since gluteus medius and minimus are attached to the pelvis in large areas, each of these two muscles are divided into three segments: anterior, middle, and posterior (Dostal and Andrews 1981). These segments and the remaining three muscles are assigned to three groups according to their position (Iglic et al. 1990): anterior (A), middle (T), and posterior (P). Tensor fasciae latae and rectus femoris are assigned to Group A and piriformis to Group P. We assume that muscle forces act along straight lines connecting the centers of muscle origin on the pelvis and the corresponding centers of muscle insertion on the femur. The coordinates of the muscle attachment points are taken from Dostal and Andrews (1981). We further assume that the force of the individual muscle is proportional to its relative cross-sectional area and its average tension, and that the average muscle tensions of individual muscles are equal in each muscle group (A, T, P). These presumptions enable us to include in the model the number of muscles that exceed the number of force and moment equilibrium equations.

The change in the hip configuration after periacetabular osteotomy is described by changes in the hip joint rotation center position in a medio-lateral direction (Δz) and a superior-inferior direction (Δx). This is done by changing the distance between the two femoral head centers and by changing the coordinates of all muscle attachment points included in the model.

The results are interpreted in terms of hip joint resultant force R. The pelvic configuration before and after periacetabular osteotomy for three different simulated postoperative situations and corresponding projections of the hip joint resultant force R in the frontal plane are shown in Figure 1. Different postoperative hip situations are characterized by different hip joint rotation-center shifts in the frontal plane of the body (Δx, Δz) caused by periacetabular pelvic osteotomy. Note that in the case (B) the acetabular fragment was only rotated around the center of the femoral head and therefore there is no rotation-center shift.

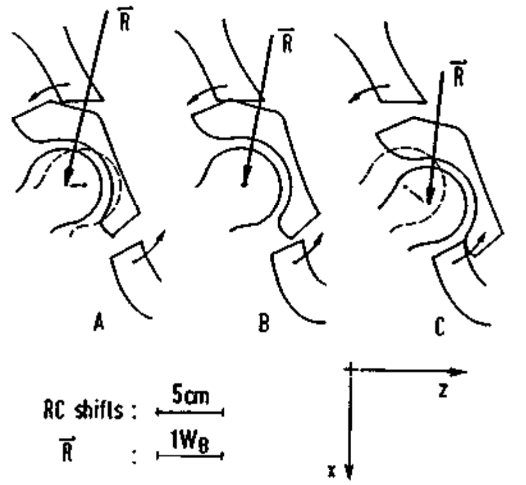

Figure 1. The pelvis configuration before (dotted line) and after periacetabular osteotomy (full line). Symbol W_B denotes body weight, while angle ϑ_{fr} characterizes the inclination of the projection of the hip joint resultant force in the frontal plane of the body toward the horizontal plane of the body. Three different simulated postoperative situations and corresponding calculated hip joint resultant forces are shown:
(A) $\Delta x = 0$, $\Delta z = -1.25$ cm, $R/W_B = 2.81$, $\vartheta_{fr} = 77.9°$,
(B) $\Delta x = \Delta z = 0$, $R/W_B = 2.38$, $\vartheta_{fr} = 81.0°$,
(C) $\Delta x = 1$ cm, $\Delta z = 1.5$ cm, $R/W_B = 1.97$, $\vartheta_{fr} = 84.8°$.
The origin of the coordinate system (x, y, z) coincides with the center of the hip joint—i.e. with the femoral head center. Projections of hip joint reaction forces in the frontal plane of the body are represented in the figure by lengths (R/W_B) and directions of the arrows (ϑ_{fr}). Hip joint rotation-center shifts in a medio-lateral direction (Δz) and superior-inferior direction (Δx), and lengths of the force vectors are scaled as indicated in the figure.

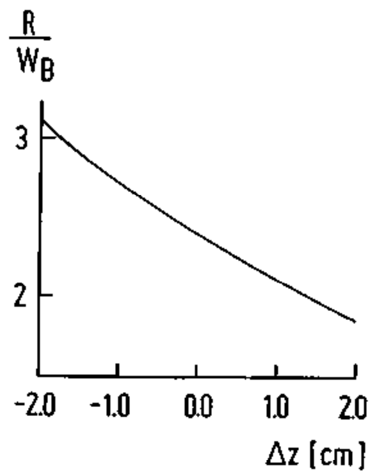

Figure 2. Magnitude of the hip joint resultant force with respect to the body weight (R/W_B) as a function of hip joint rotation center shifts in a medio-lateral direction (Δz) for $\Delta x = 0$.

Results

We found that the rotation-center shift in the superior-inferor direction (Δx) has very little influence on the resultant hip joint force, whereas rotation-center shift in the medio-lateral direction (Δz) has a considerable influence. The continuous dependence of the magnitude of the hip joint resultant force R on rotation-center shift in a medio-lateral (Δz) direction is presented in Figure 2. The hip joint resultant force can be diminished appreciably by shifting the rotation center medially.

Discussion

Our results indicate that rotation-center shift in the superior-inferior direction as a consequence of periacetabular osteotomy has nearly no influence on the magnitude of the hip joint resultant force and therefore neither on the corresponding pressure on the femoral head. We show, however, that the simulated rotation-center shift in the medio-lateral directions has a substantial effect on the hip joint resultant force. By assuming that an increased hip joint resultant force may cause development of arthrosis, and by taking into account that medialization of the rotation-center causes a decrease in the hip joint resultant force, we concluded that medialization is favorable. Lateralization, on the other hand, increases the hip joint resultant force; this should be avoided while performing periacetabular osteotomy.

References

Dostal W F, Andrews J G. A three dimensional biomechanical model of hip musculature. J Biomech 1981; 14 (11): 803–12.

Ganz R, Klaue K, Vinh T S, Mast J W. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. Clin Orthop 1988; 232: 26–36.

Iglic A, Srakar F, Antolic V, Kralj Iglic V, Batagelj V. Mathematical analysis of Chiari osteotomy. Acta Orthop Iugosl 1990; 20: 35–9.