# THE REQUIRED RESULTANT ABDUCTOR FORCE AND THE AVAILABLE RESULTANT ABDUCTOR FORCE AFTER OPERATIVE CHANGES IN HIP GEOMETRY

V. ANTOLIČ[1,4], A. IGLIČ[2,3,4], S. HERMAN[1,4], F. SRAKAR[1,4], V. KRALJ IGLIČ[3], A. MAČEK LEBAR[1], U. STANIČ[4]

**The required abductor force ($\vec{F}_{req}$) and the available abductor force ($\vec{F}_{av}$) are calculated for different positions of the hip rotation center (RC) and different greater trochanter (GT) shifts in the frontal plane of the body in the one-legged stance. It is biomechanically favorable that $F_{av}$ exceeds $F_{req}$ and that the magnitude of the resultant hip joint force (R) after the operation is decreased. The difference between $F_{av}$ and $F_{req}$, which represents the relative abductor strength, increases after medialization of RC and after lateralization of GT. On the contrary, after medialization of GT and after lateralization of RC, the difference decreases, which has unfavorable biomechanical effects. Distalization of GT is favorable because it increases the relative abductor strength.**

**Keywords** : hip ; muscle force ; biomechanics.
**Mots-clés** : hanche ; force musculaire ; biomécanique.

## INTRODUCTION

The hip abductor resultant force opposing the moment of body weight in the one-legged stance is dependent on the body weight and the geometry of the hip (8, 9). The geometry of the hip can be changed operatively, leading to a new position of the hip rotation center (RC) and/or to a new position of the greater trochanter (GT). Via the length of the lever arms the positions of RC and GT influence the required hip abductor muscle forces, which are needed to keep the pelvis level in the one-legged stance. Therefore, the resultant hip abductor muscle force ($\vec{F}_{req}$) is also dependent on the positions of RC and GT (8, 9). On the other hand, the positions of RC and GT determine the available resultant force of hip abductors ($\vec{F}_{av}$), which is dependent on the muscle length (10). The influence of the positions of RC and GT on $\vec{F}_{req}$ has already been intensively studied before (8, 9). In the present work we shall in addition study simultaneously the influence of the positions of RC and GT on both $\vec{F}_{req}$ and $\vec{F}_{av}$.

Under normal conditions, $F_{av}$ exceeds $F_{req}$, R is proportional to $F_{req}$, and no abductor weakness is observed. Yet, when $F_{req}$ exceeds $F_{av}$, pelvic tilting can occur in the one-legged stance due to the relative abductor weakness. In the latter case, R is proportional to $F_{av}$ and no longer to $F_{req}$ ; therefore the magnitude of R is smaller than it would be if R were proportional to $F_{req}$.

In this study we were interested to know how RC and GT shifts in the frontal plane of the body affect $F_{req}$ and $F_{av}$ in the one-legged stance. By taking into account the values of both these forces, the magnitudes of R and of the abductor muscle force can be evaluated.

## METHODS

A simple static 3-dimensional mathematical model of the hip is used in this work to calculate the hip

[1] Department of Orthopedic Surgery, Medical Faculty, Zaloška 9,
[2] Faculty of Electrical and Computer Engineering, Tržaška 25,
[3] Institute of Biophysics, Medical Faculty, Lipičeva 2,
[4] "J. Stefan" Institute, Jamova 39,
61000 Ljubljana, Slovenia.
Correspondence and reprints : V. Antolič.

joint reaction force ($R$) and the vector sum of the hip abductor muscle forces required to perform mechanical equilibrium of the body (i.e. the required resultant hip muscle force $\vec{F}_{req}$) in the one-legged stance. The model has been presented in detail by Iglič *et al.* (5, 6) ; therefore, only a brief review of the model is given here.

The model is defined by means of force and moment equilibrium equations. The piriformis, gluteus medius, gluteus minimus, rectus femoris and tensor fasciae latae muscles are included in the model because of their important role in maintaining the stable one-legged stance. It is assumed that muscle forces act along a straight line connecting the centers of muscle origins on the pelvis and the corresponding centers of the muscle insertions on the femur. The reference coordinates of muscle attachment points determined by Dostal and Andrews (4) are used. $\vec{R}$ and $\vec{F}_{req}$ are calculated by solving the model force and the moment equilibrium equations (5, 6).

The maximal available resultant hip muscle force $\vec{F}_{av}$ is the vector sum of the maximal available forces of individual muscles. The magnitude of the maximal available force of individual muscles ($F_{i,av}$) is estimated by using the approximate linearized relation (10) :

$$F_{i,av} = \sigma_{eff} A_i \left[ 1.25 \frac{l_i}{l_{i,r}} + 0{,}5 \right], \qquad (1)$$

where $\sigma_{eff}$ is the effective maximal muscle tension (in this study $30N/cm^2$ (7)), $A_i$ is the physiological cross-sectional area of the i-th muscle [determined from references (4), (5), (6) and (10)], $l_{i,r}$ is the reference length of the i-th muscle before displacement of RC or GT which is defined by the reference coordinates of the center of muscle origin on the pelvis and the corresponding center of the muscle insertion on the femur, while $l_i$ is the actual length of the i-th muscle after displacement of RC or GT.

For the calculation of $\vec{F}_{req}$, $\vec{F}_{av}$ and $\vec{R}$ the variation of the greater trochanter position is mathematically simulated (2) by changing the coordinates of the muscle attachment points on the greater trochanter in the medial, lateral, distal and proximal directions with respect to the corresponding reference coordinates of Dostal and Andrews (4), which define the reference pelvic shape.

The hip joint rotation center shift is simulated by variation of the reference coordinates of the muscle attachment points and by variation of the interhip distance (5, 11).

## RESULTS

The difference between the available abductor force ($F_{av}$) and the required abductor force ($F_{req}$) is noted as a relative abductor strength, which is positive and tends to increase with medialization of RC (fig. 1a), distalization of RC (fig. 1b) and lateralization/distalization of GT (fig. 2). Distalization of GT tends to increase both $F_{req}$ and $F_{av}$, but the slope of change for $F_{av}$ is steeper, leading to a biomechanically favorable effect of GT distalization on hip function.

## DISCUSSION AND CONCLUSIONS

During gait and in the one-legged stance $F_{av}$ normally exceeds $F_{req}$. When $F_{req}$ exceeds $F_{av}$, the magnitude of the resultant hip joint contact force (R) becomes dependent on $F_{av}$ and no longer depends on $F_{req}$. The reason is that $F_{av}$ is the maximal force that can be developed by the hip abductors, and is smaller than $F_{req}$. When $F_{req}$ exceeds $F_{av}$, abductor weakness occurs, manifested clinically by a positive Duchenne and/or Trendelenburg sign. The biomechanically favorable effects of surgery include a decrease in R and a simultaneous increase in the relative abductor strength.

In total hip replacement and in pelvic osteotomies a change in the position of RC and GT may occur. Proximal femoral osteotomies and GT osteotomies (3) bring about changes in the GT space position. R is decreased with a simultaneous increase in the relative abductor strength in GT lateralization and RC medialization. Distalization of GT causes an increase in the relative abductor strength and in the magnitude of the resultant hip joint force R. As suggested, an increased R could be responsible for an increased incidence of loosening after total hip replacement (1, 3) and for progression of osteoarthritis (8, 9). Increasing the magnitude of R after pelvic operations should be avoided whenever possible.

The most adverse biomechanical effects include lateralization of RC and medialization of GT, which both decrease the relative abductor strength and increase R. Proximalization of GT and/or RC decreases the relative abductor strength and R.

In theory distalization of RC is favorable, as it increases the relative abductor strength, yet it is clinically very difficult to perform for various reasons.

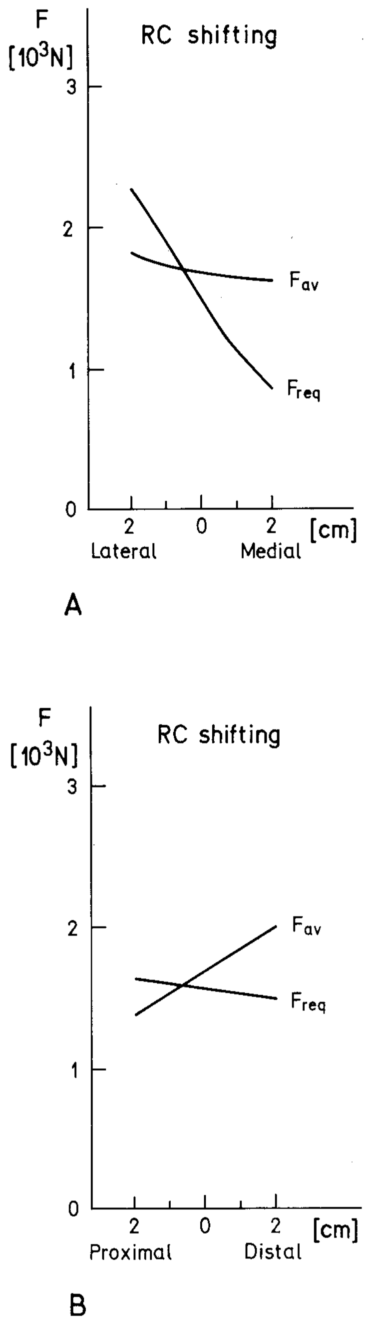


***Fig. 1.*** — The magnitude of required ($F_{req}$) and available ($F_{av}$) resultant abductor forces depending on RC shifts in the mediolateral direction (A) and proximal-distal direction (B).

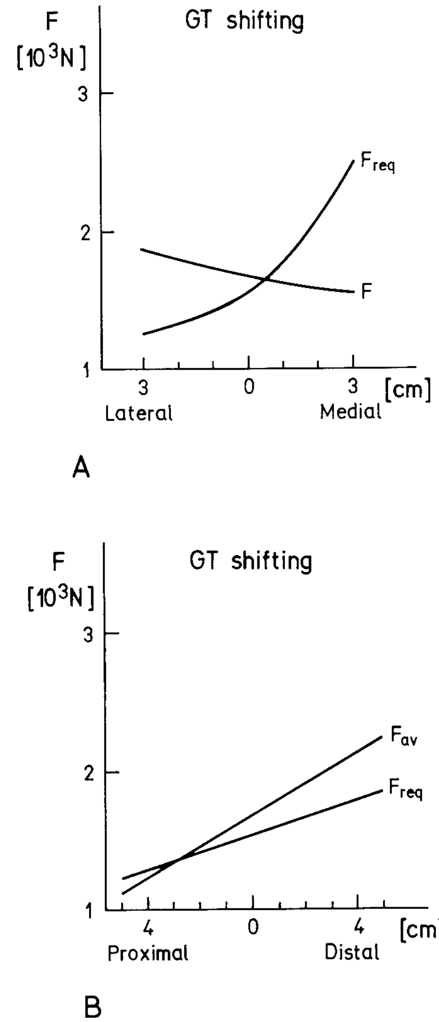


***Fig. 2.*** — The magnitude of required ($F_{req}$) and available ($F_{av}$) resultant abductor forces depending on GT shifts in the mediolateral direction (A) and proximal-distal direction (B).

We would conclude that operative changes in hip geometry may considerably affect the resultant hip joint force and the relative abductor strength. Any eventual shifting of RC and GT after total hip replacement should be carefully planned, especially in cases of preoperative abductor weakness. Medialization of RC and lateralization of GT always have favorable biomechanical effects on hip function, while the preoperative planning should always avoid lateralization of RC and/or medialization of GT.

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## SAMENVATTING


*V. ANTOLIČ, A. IGLIČ, S. HERMAN, F. SRAKAR, V. KRALJ IGLIČ, A. MAČEK LEBAR, U. STANIČ. De nodige en beschikbare abduktiekracht na chirurgische wijziging van de heup geometrie.*

De vereiste abduktiekracht ($F_{req}$) en de beschikbare abduktiekracht ($F_{av}$) worden berekend in de verschillende standen van het rotatiecentrum van de heup (RC) en bij verplaatsingen van de trochanter major (GT) in het frontaal vlak, in monopodale stand. Als biomechanisch gunstig wordt aangenomen dat de $F_{av}$ groter is dan de $F_{req}$ en dat de grootte van de postoperatieve resulterende kracht (R) vermindert. Het verschil tussen de $F_{av}$ en de $F_{req}$, die de relatieve abduktiekracht vertegenwoordigt, vermeerdert bij medialisatie van RC en lateralisatie van de GT. Bij de medialisatie van GT en lateralisatie van RC vermindert het verschil tot negativatie met ongunstig biomechanische effekt. De verplaatsing van GT naar distaal is gunstig en gevolgd met een vermeerdering van de relatieve abductiekracht.


## RÉSUMÉ


*V. ANTOLIČ, A. IGLIČ, S. HERMAN, F. SRAKAR, V. KRALJ IGLIČ, A. MAČEK LEBAR, U. STANIČ. La force abductrice requise et la force abductrice disponible après modifications opératoires dans la géométrie de la hanche.*

La force abductrice requise ($F_{req}$) et la force abductrice disponible ($F_{av}$) sont calculées pour différentes positions du centre de rotation de la hanche (RC) et pour les déplacements du grand trochanter (GT) dans le plan frontal du corps en appui monopodal. Il est biomécaniquement favorable que la $F_{av}$ dépasse la $F_{req}$ et que la grandeur de la résultante des forces s'exerçant sur l'articulation de la hanche (R) soit diminuée après l'opération. La différence entre $F_{req}$ et $F_{av}$, qui représente la force abductrice relative augmente après médialisation du RC et latéralisation du GT. Après médialisation du GT et latéralisation du RC la différence diminue et devient négative, ce qui produit des effets biomécaniques défavorables. La distalisation du GT est favorable parcequ'elle augmente la force d'abduction relative.