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Biomechanical study of various greater trochanter positions

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Abstract A mathematical model was used in order to evaluate the mechanical situation after lateral, medial, distal and proximal displacements of the greater trochanter. It was calculated that lateral displacement may considerably reduce the hip joint contact force, while medial displacement greatly increases it. The influence of proximalization and distalization is much less pronounced. It was further shown that, regarding the postoperative relative hip abductor muscle strength, lateral and distal displacements of the greater trochanter are favourable, while proximal and medial displacements are not.

Introduction

The tip of the greater trochanter (GT) is normally at the level of the centre of the femoral head. Its position can be changed intentionally during a surgical procedure or concomitantly as a side-effect of an operation for some other purpose. Intentional change occurs in various osteotomies in which the GT is always displaced laterally and/or distally. However, medialization and proximalization of the GT are never performed intentionally but can occur after, for example, valgus intertrochanteric osteotomy or total hip replacement using a prosthesis with a short femoral head stem offset. Medialization of the GT can also be the consequence of a short femoral neck as, for example, in the case of slipped capital femoral epiphysis or Perthes' disease. Varus osteotomy can lead to a slight proximalization of the GT. Proximal shift may also occur in cases of femoral neck growth disturbances like congenital hip dislocation, Perthes' disease and coxa vara congenita. Lateral shift occurs after implanting a total hip prosthesis with a long femoral head stem offset [1]. The extreme distal position of the GT is very rare, but it may arise subsequent to growth arrest of the GT epiphysis resulting from iatrogenic damage, for example, after intramedullar instrumentation.

It is commonly agreed that the reduction of the vector sum of the hip abductor muscle forces required to achieve mechanical equilibrium of the body (the required resultant hip muscle force $\vec{F}_{req}$) and the reduction of the corresponding hip joint contact force $\vec{R}$ after various surgical interventions in the hip are favourable [9, 10, 15, 17]. Reduction of the hip joint contact force is associated with simultaneous diminution of the hip joint contact pressure, which may slow the progress of osteoarthrosis [5, 12, 14]. Also, a high value of the hip joint contact force is most probably one of the factors causing loosening of a total hip prosthesis [1], due to mechanical reasons (increased interface stresses) and/or the increased amount of polyethylene debris causing particle disease. Using these criteria, it was concluded that lateral displacement of the GT is beneficial because it diminishes the magnitude of the hip joint contact force (R) and the magnitude of the required resultant muscle hip force (F_{req}) [9, 11].

However, that the hip joint contact force and the required resultant hip muscle force are minimal is not sufficient to estimate the efficiency of a planned operation. In particular, while performing certain surgical interventions in the hip, some muscle attachments became translocated, and therefore the lengths of the muscles are changed. As a consequence, the maximal available forces of these muscles are also altered [2, 7]. This is important because the vector sum of the maximal available hip abductor muscle forces ($\vec{F}_{av}$) could be considerably different after the operation. When the magnitude of $\vec{F}_{av}$ becomes smaller than the magnitude of the required resultant hip muscle force $\vec{F}_{req}$, the relative muscle strength decreases to such an extent that lurch appears and/or the Trendelenburg sign becomes positive.

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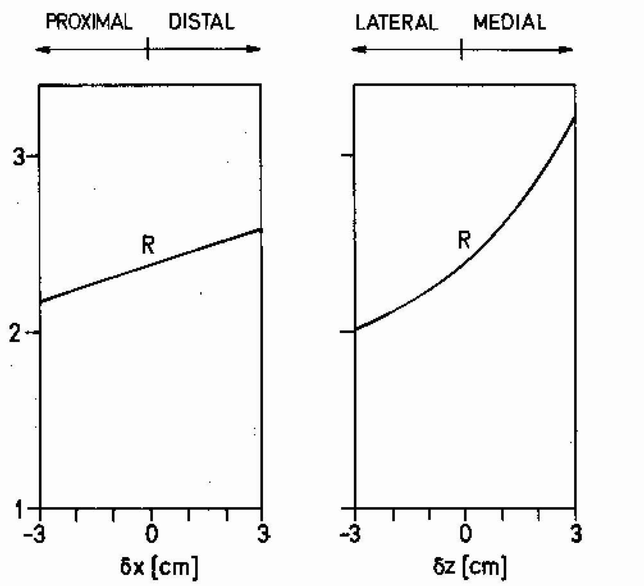

Fig. 1 Dependencies of the magnitude of the hip joint contact force *(R)* on displacements of the greater trochanter in the proximal, distal, lateral and medial directions. All calculated values of *R* are normalized with respect to the magnitude of the body weight force

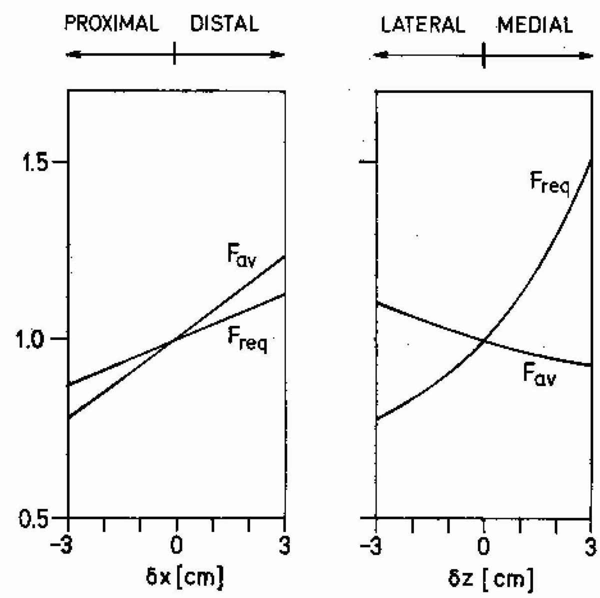

Fig. 2 Dependencies of the relative magnitude of the required resultant hip muscle force $[F_{req}/F_{req}\ (\delta x = \delta z = 0)]$ and the relative magnitude of the maximal available resultant hip muscle force $[F_{av}/F_{av}\ (\delta x = \delta z = 0)]$ on the displacements of the greater trochanter in the proximal, distal, lateral and medial directions

Therefore, in this work a comprehensive biomechanical study of the various positions of the GT in the frontal plane was undertaken which simultaneously considered the postoperative values of the required resultant hip muscle force, the maximal available resultant hip muscle force and the hip joint contact force.

Methods

In order to calculate the hip joint contact force $\vec{R}$ and the required resultant hip muscle force $\vec{F}_{req}$, a simple, static, three-dimensional mathematical model of an adult human hip in the one-legged stance was used. The model is defined by means of force and moment equilibrium equations and takes into account nine hip muscles. It is described in detail elsewhere [6–8].

The maximal available resultant hip muscle force $\vec{F}_{av}$ is the vector sum of the maximal available forces of the individual muscles. In this work, the linear relation between the magnitude of the individual maximal available muscle force and the muscle length [7, 16] is used to calculate the former. The validity of this relation is limited by the assumption that during the one-legged stance the hip muscles operate on the ascending region of their force-length curve [16].

While calculating $\vec{F}_{req}$, $\vec{F}_{av}$ and $\vec{R}$, the variation of the GT position is mathematically simulated by changing the coordinates of the muscle attachment points on the GT in the proximal ($\delta x < 0$), distal ($\delta x > 0$), lateral ($\delta z < 0$) and medial ($\delta z > 0$) directions with respect to the corresponding reference coordinates taken from Dostal and Andrews [3].

Results

The results are interpreted with regard to the dependencies of the magnitudes of the hip joint contact force $\vec{R}$ (R), the required resultant hip muscle force $\vec{F}_{req}$ (F_{req}) and the maximal available resultant hip muscle force $\vec{F}_{av}$ (F_{av}) on the various GT displacements. The continuous dependencies of R on the proximal, distal, lateral and medial displacements of the GT are presented in Fig. 1, while those of F_{req} and F_{av} are presented in Fig. 2.

Discussion

The presented results show that various GT displacements may have a considerable effect on the maximal available resultant hip muscle force $\vec{F}_{av}$, on the required resultant hip muscle force $\vec{F}_{req}$ and on the hip joint contact force $\vec{R}$. The magnitudes of $\vec{F}_{req}$ and $\vec{R}$ change after the displacement of the GT because the moment arm of the body weight force and the moment arms of the hip abductor muscle forces are altered.

It was calculated that after the lateral displacement of the GT the magnitude of the required resultant hip muscle force (F_{req}) and the magnitude of the hip joint contact force (R) may be considerably reduced, while the magnitude of the maximal available resultant hip muscle force (F_{av}) is increased. This is favourable because the hip joint contact pressure is thus lowered and the relative hip abductor muscle strength (the difference between F_{av} and F_{req}) augmented.

Distalization of the GT is usually performed together with lateralization rather than as an isolated surgical procedure. Distal displacement of the GT increases F_{req}, R and also F_{av}. However, the increase in F_{av} is more pronounced than the corresponding increase in F_{req} (see Fig.

2). In this way, the preoperative positive Trendelenburg sign (if present) could become negative and/or lurch may disappear after the operation. This phenomenon was recently actually observed in patients [4].

Medialization of the GT is biomechanically disadvantageous because it simultaneously increases F_{req} and R and diminishes F_{av} (see Figs. 1 and 2), which is the most unfavourable combination. Therefore, it is suggested that medialization of the GT should always be avoided.

Proximalization of the GT diminishes F_{req}, R and also F_{av}. However, the decrease of F_{av} is more pronounced than the corresponding decrease of F_{req} (Fig. 2). The decrease of F_{av} with proximal displacement of the GT is in accordance with experimental observations. It has been shown that the strength of the hip abductor muscles, measured with a load-cell device, was significantly reduced if the patients' GT was proximally displaced during total hip replacement [13]. The significant decrease of the magnitude of the maximal available resultant hip muscle force F_{av} after proximal displacement is unfavourable because in this way the Trendelenburg sign could become positive and/or lurch may appear after the operation due to F_{av} being smaller than F_{req} (see Fig. 2). These phenomena have actually been observed in patients suffering proximal displacement after total hip replacement due to poor fixation of the GT [13].

In conclusion, we would like to emphasize that in transposition of the GT lateralization is the most favourable option, while distalization is favourable only within the range in which the hip joint contact force is not considerably increased. Significant proximalization of the GT is disadvantageous because it decreases the relative hip abductor muscle strength. Medialization of the GT should be minimized as much as possible because it greatly increases the hip joint contact force and significantly decreases the relative hip abductor muscle strength.

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