J. Anat. (1989), **166**, pp. 179–189
With 8 figures
Printed in Great Britain

The functional anatomy of tensor fasciae latae and gluteus medius and minimus

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(*Accepted* 21 *February* 1989)

INTRODUCTION

The accurate anatomical description of the musculoskeletal system has been the precursor and basis for the understanding of the biomechanics and functional anatomy of the different parts of the human body. This has not been the case for the hip abductor mechanism.

The conventional description of the anatomy of the gluteus medius is a broad, thick radiating muscle on the outer surface of the pelvis. Its attachment is described as being between the iliac crest and the gluteal line. The fibres are said to converge to a strong flattened tendon which is inserted into the oblique ridge on the lateral surface of the greater trochanter, with a bursa separating the tendon from the surface of the trochanter (Clemente, 1985; Romanes, 1981). Similarly, the gluteus minimus is fan-shaped, arising from the outer surface of the ilium, and its fibres converge into a tendon that inserts at the anterior border of the greater trochanter.

In the standard descriptions of the nerve supply to these muscles, the superior gluteal nerve is said to provide branches to innervate the muscles. The gluteus medius is described as a strong abductor and medial rotator of the thigh. During the stance phase of gait, the gluteus medius is supposed to prevent the sagging of the pelvis on the unsupported side. The action of gluteus minimus is said to be similar to that of gluteus medius.

The widely accepted mathematical models of the mechanics of the gluteus medius and minimus are those based on the model originally described by Fick in 1910 (Bombelli, 1983) and later adopted by Pauwels (1976) and Maquet (1985). These are static two-dimensional models that substitute an arbitrary force vector for the total action of gluteus medius and minimus. The vectors originate at an arbitrary point on the outer surface of the iliac bone at the level of the gluteal line and end at the proximal part of the lateral surface of the greater trochanter. The abductor moment arms that have been calculated, based on these models, are not accurate as they do not take into account the overall shape and action of the muscles. Consequently the theoretical predictions of these models are not always borne out by the clinical findings.

In the past two decades several papers on anatomy, mechanics and functional performance of the hip muscles and abductor mechanism have been published (Bombelli, 1983; Borja, Latta, Stinchfield & Obreron, 1985; Crowninshield, Johnston, Andrews & Brand, 1978; Dostal & Andrews, 1981; Dostal, Soderberg & Andrews, 1986; Inman, 1947; Kelikian, Tachdjian, Askew & Jasty, 1983; Maquet, 1985). Some of the experimental studies reported by these authors present observations that reveal the disparity between the functional reality and the biomechanical model of the system. The studies by Jensen & Davy (1975) on the muscle lines of action, Clark & Haynor (1987) on the anatomy of abductor muscles and Soderberg & Dostal (1978), Lyons *et al.* (1983) and Wilson, Capen & Stubbs (1976) on fine wire electromyographic investigation of the abductor muscles provide new information on the anatomy, mechanics and functions of these muscles. However, review of these papers revealed the absence of a satisfactory anatomical and dynamic model to explain adequately the findings of these studies, and thus did not allow those authors to draw valid conclusions. The attempt by some of the authors to explain and interpret the data and observations according to the accepted static two-dimensional model resulted in contradictory statements (Kelikian *et al.* 1983; Nutton & Checketts, 1984).

In numerous clinical and surgical texts it has been stated that the glutei abduct the hip or prevent the pelvis from sagging (Clemente, 1985; Borja *et al.* 1985; Dostal & Andrews, 1981; Inman, 1947; Hardcastle & Nade, 1985; Heath, 1984; Kelikian *et al.* 1983). In addition, it has been stated that a valgus osteotomy (increasing angle of femoral neck) will increase the muscle length and shorten the lever arm, and conversely, that a varus osteotomy (decreasing angle of femoral neck) will shorten the muscle but that this is offset by lengthening the lever arm (Maquet, 1985; Schneider, 1984). A careful examination of the reported clinical experiences of these procedures shows that in the majority of those cases, the valgus osteotomy will do better than the varus osteotomy of the hip when assessed over a period of time. Frequently, the poor results after varus osteotomy are noticed within a few months, whereas the valgus osteotomies may function satisfactorily for several years (Bombelli, 1983; Maquet, 1985; Schneider, 1984).

The purpose of this study was to define the functional anatomy of the hip abductor mechanism and correlate the findings with a biomechanical model.

MATERIALS AND METHODS

The intact gluteal area consisting of pelvis and proximal femur was dissected in 11 cadavers (6 fresh and 5 preserved). The attachments of the muscles were noted proximally and distally. The shape of the muscle and the orientation of the muscle fibres were defined. In addition, the superior gluteal nerve and vessels were traced from the sciatic notch and followed into the muscle bellies. The volume of each part of the gluteus medius was measured separately.

Based on the anatomical findings, a new biomechanical model was developed to explain the normal and pathological findings of the hip abductor mechanism. Electromyographic studies of the tensor fasciae latae and the gluteus medius were done in ten normal subjects, during the gait cycle and in isolated abduction of the lower limb. Surface electrodes were used in all subjects as good correlation had been obtained with fine wire electrodes in four subjects. This has been corroborated by a previous study (Kadaba, Wootten, Gainey & Cochran, 1985).

RESULTS

The proximal attachment of the gluteus medius was noted to be from the anterior superior iliac spine, along the outer edge of the iliac crest to the posterior superior iliac spine. The line of attachment is approximately 1 cm broad and limited to the iliac crest. There is no significant attachment of the rest of the muscle to the iliac blade and the fibres are separated from the periosteum by loose fibrous tissue.

Fig. 1. Cadaver specimen showing the three distinct parts of gluteus medius: (A) anterior part, (B) middle part, (C) posterior part.

The gluteus medius is curved and fan-shaped and tapers to a strong tendon which is attached to the anterosuperior portion of the greater trochanter and not to the lateral aspect. The distal attachment is well defined and is approximately 1 cm wide by 3 cm long. The muscle bulk has three distinct parts making up the fan shape (Fig. 1). The three parts are equal in volume and the divisions between the parts are best seen in the fresh specimens although they can be readily identified in the preserved cadaver.

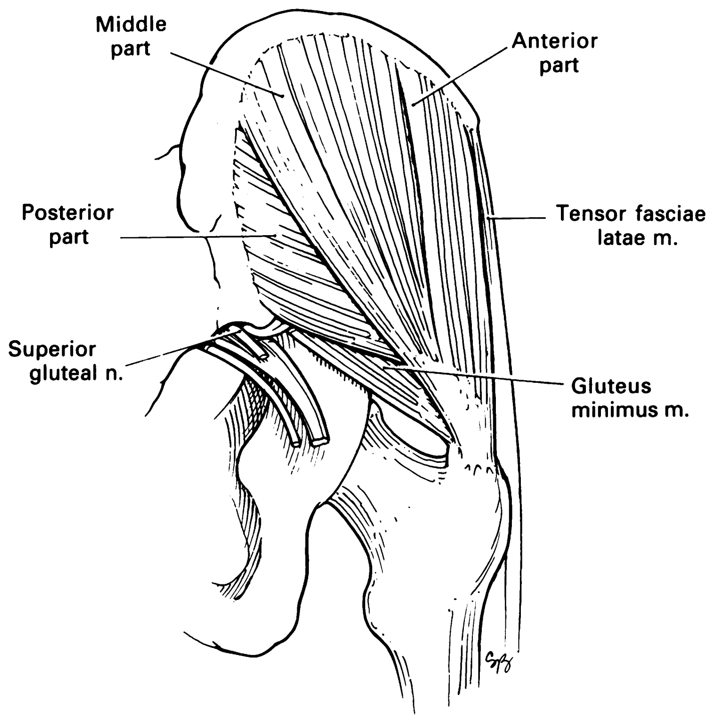

Fig. 2. Schematic drawing of the three parts of gluteus medius. The direction of the muscle fibres of each part determines the line of pull of that individual segment.

The fibres of the more horizontal or posterior part run almost parallel to the neck of the femur. The anterior part has fibres running almost vertically from the anterior iliac crest to the top of the trochanter. The fibres of the middle part also tend to be more vertically orientated. Figure 2 shows a posterior view of the gluteus medius with the mean direction of the muscle fibres in each part. The posterior part is parallel to the femoral neck, while the anterior part has a nearly vertical direction.

The superior gluteal nerve may divide as it emerges from the greater sciatic notch, or run along the middle gluteal line, and give off separate branches to each of the three parts of the gluteus medius and a separate branch each to the gluteus minimus and tensor fasciae latae. More commonly the branch to the posterior part arises in the sciatic notch (Figs. 3, 4). These variations were noted in six of the specimens. The gluteus medius is innervated from its deep surface whereas the gluteus minimus is innervated from its superficial surface.

The gluteus minimus (Fig. 4) attaches proximally from the anterior inferior iliac spine to the posterior inferior iliac spine, along the middle gluteal line. Its distal attachment is on the inner aspect of the anterosuperior margin of the greater trochanter. The fibres of this muscle tend to be horizontally orientated and run parallel to the neck of the femur.

The electromyographic studies showed a phasic action of the three parts of the gluteus medius from posterior to anterior with the tensor fasciae latae being most active during full stance. In isolated abduction, gluteus medius did not show strong electromyographic activity and in some subjects no activity was seen, while tensor fasciae latae showed intense activity.

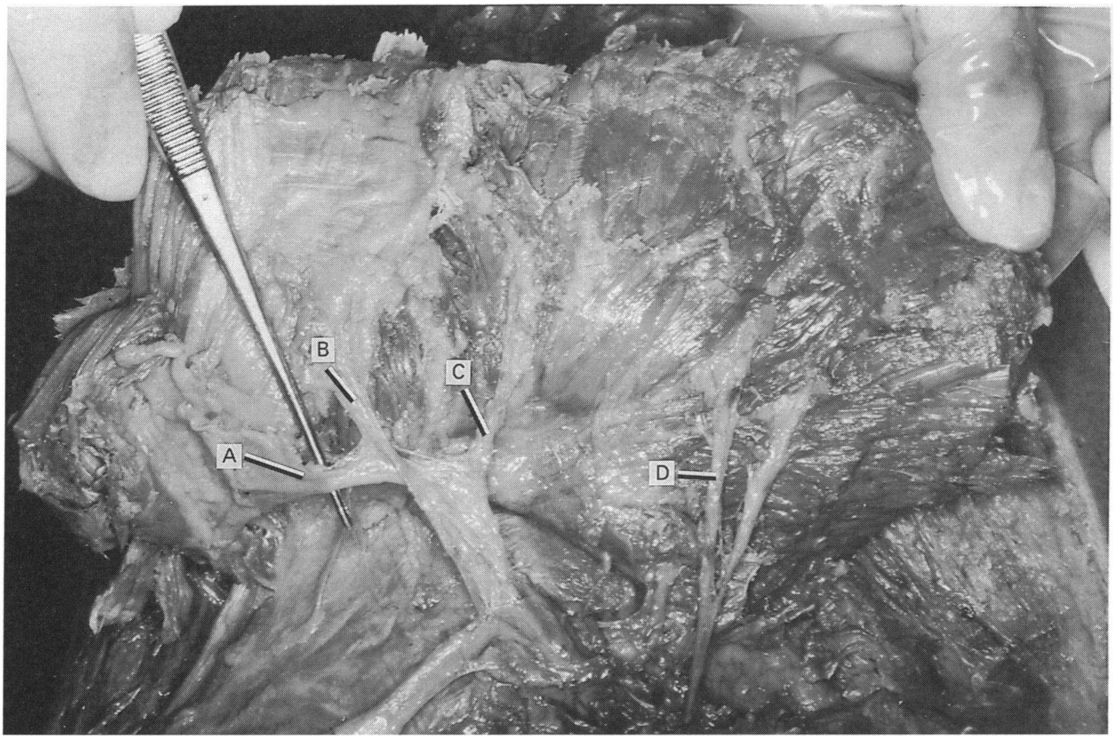

Fig. 3. Specimen of gluteus medius reflected to show independent innervation of each part. The direction of the fibres in each part can be well seen with the anterior part on the left and posterior part on the right. The posterior part running horizontally to the right is separately innervated by a branch (D) of the superior gluteal nerve. The middle part fibres and nerve (C) are orientated between those of the vertical anterior (B) and the horizontal posterior parts. The nerve to tensor fasciae latae (A) is supported by the forceps.

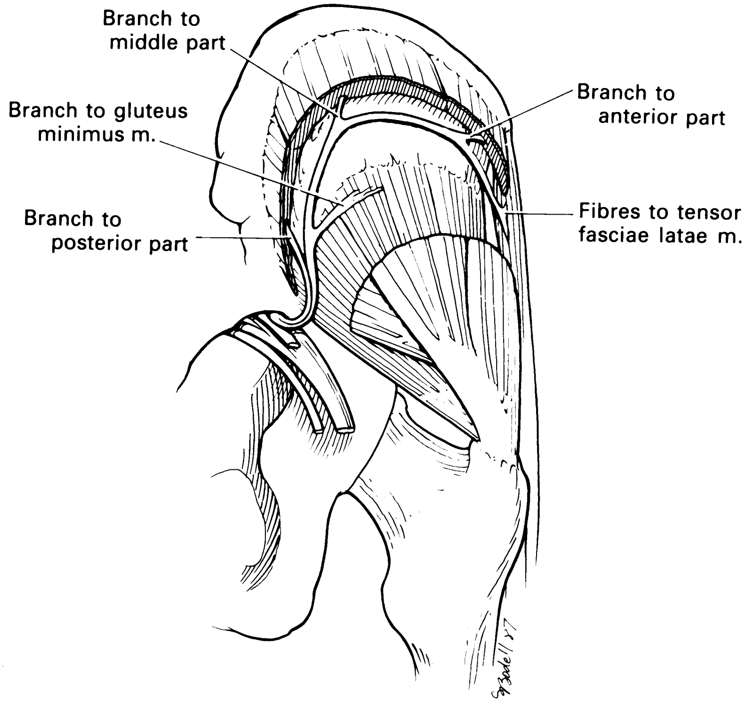

Fig. 4. Schematic drawing of the innervation of the glutei.

As a result of the anatomical and electromyographic findings, we have developed a three-dimensional biomechanical model and a new hypothesis on the action and function of the gluteus medius and tensor fasciae latae.

DISCUSSION

The classical description of the anatomy of the gluteus medius and minimus considers them each as a single muscle mass with one innervation for each muscle with an on–off mass action. Functionally, they are defined as the main hip abductors. We propose a new model of the anatomy and function of the glutei, whereby the gluteus medius is a segmented muscle with each part separately innervated and with a phasic action in different directions. In addition, we define the functions of gluteus medius and minimus primarily as hip stabilisers and pelvic rotators and regard their role in the initiation and assistance in abduction as a secondary function. This would explain the waddling gait with congenitally dislocated hips and the swinging of the buttocks during normal walking. The primary function of hip abduction would then be via the tensor fasciae latae muscle.

Biomechanically the traditional two-dimensional static models of the abductor mechanism substitute a single force vector for the total action of the gluteus medius and minimus. Apart from the assumption of the combined mass action of gluteus medius and minimus and convenience in sketch drawings, the choice of the point of application of this vector is arbitrary (Bombelli, 1983) and has no anatomical significance. The models fail to satisfy the mechanical requirements of the functional performance of a dynamic system, or to explain the observed clinical results.

We postulate that the gluteus medius and minimus function primarily as hip stabilisers and pelvic rotators, rather than hip abductors. As mentioned above, the gluteus medius is made up of three parts of approximately equal volume with three distinct muscle fibre directions and separate innervations. This anatomical configuration suggests a different function for each of the three parts rather than a total single muscle action. The EMG study showed that the functions of the three parts are phasic and related to different gait determinants.

In 1895 Trendelenburg described the inability of the glutei to function in patients with congenital dislocation of the hip. He noted also the weakness of the glutei in progressive muscular atrophy, with the swaying gait but the absence of waddling. Of importance is Trendelenburg's recognition, at that time, of three parts to the gluteus medius. He described anterior, middle and posterior parts clinically and the directions these muscle groups followed in the abnormal situation (Rang, 1966). Brash (1955) diagrammatically showed three parts in the gluteus medius and noted that two or three branches of the superior gluteal nerve entered the deep surface of the muscle, and that one branch could arise before the nerve emerged from beneath the piriformis muscle.

These more accurate anatomical descriptions have not been used subsequently. Even the more elaborate investigational methods used by some recent authors have not revealed this important structural division of the gluteus medius (Jensen & Metcalf, 1975; Jensen, Smidt & Johnston, 1971).

Relying on a computer-based model, Soderberg & Dostal (1978) concluded that for geometrical reasons there are three segments to the gluteus medius muscle. They examined electromyographically the three segments and showed that the gluteus medius is active in the stance phase and that the three parts of the muscle fire sequentially. The posterior part fires first at the beginning of stance phase (heel strike) and continues until the point of toe-off. The anterior part showed the maximum

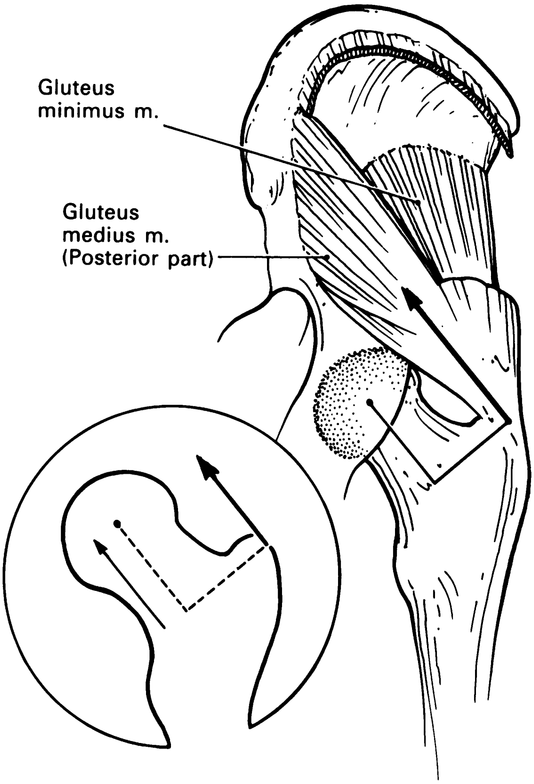

Fig. 5. Diagram showing the posterior part of gluteus medius and part of gluteus minimus with the corresponding force vector. These muscles pull the femoral head into the acetabulum on the weight-bearing side and are responsible for hip joint stability during gait.

activity during stance and single support phase. Although the insertions of the fine wire electrodes were not at the anatomical location of the motor points, the general trend of the muscle activity as related to the gait cycle is accurate. These results confirm the segmental and phasic function of the gluteus medius.

Because of the anatomical configuration of the glutei and as a result of our electromyographic study, we believe that the primary function of the posterior part of the gluteus medius and the whole of gluteus minimus is to stabilise the femoral head in the acetabulum in different positions of rotation of the femoral head and during different parts of the gait cycle (Fig. 5). The force generated by these muscles applied along their line of action will pull the head of the femur into the acetabulum, resulting in a stable ball and socket joint. The posterior part also helps in the initiation of load transfer from one leg to the other. Figure 5 shows the force vector arrangements that stabilise the hip joint during the weight-bearing and swing phases of the gait cycle.

The anterior and middle parts of the gluteus medius have a more vertical pull and help initiate abduction which is then completed by the tensor fasciae latae. The increase in activity of the anterior part from the midstance (Soderberg & Dostal, 1978) which is coincident with the initiation of pelvic rotation, when combined with the geometrical configuration and the line of action of this part, suggests the anterior part of the gluteus medius as the primary pelvic rotator.

Figures 6 and 7 show the functional arrangement of the abduction mechanism. A hypothetical triangle shows the point of application of the forces of the tensor fasciae

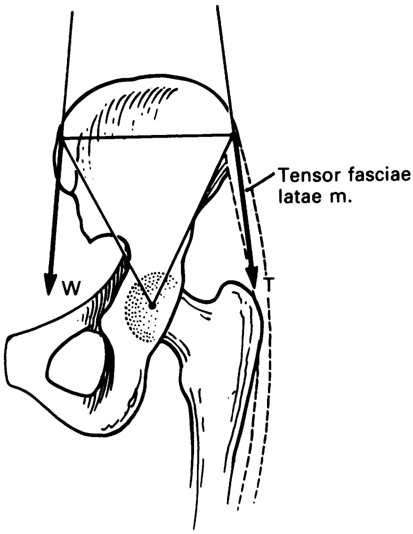

Fig. 6. Posterior projection of the action of tensor fasciae latae during the full stance phase of the gait cycle. The tensor fasciae latae is the major abductor and holds the pelvis horizontal during the stance phase of gait. (See text for description.)

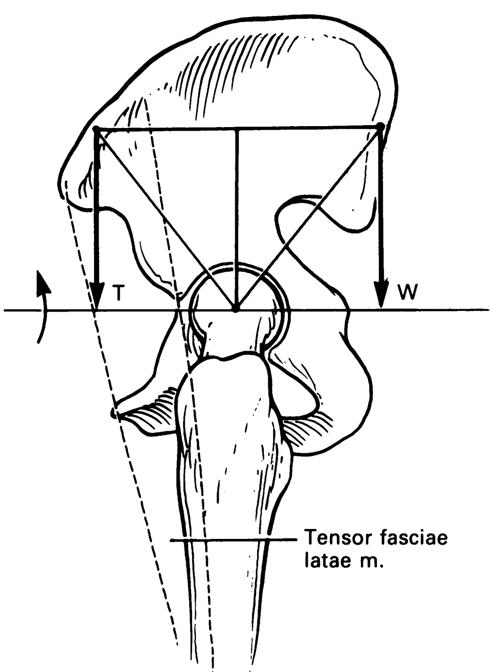

Fig. 7. Lateral projection of the hypothetical triangle showing the balance between the force of the body weight (W) through the centre of the sacroiliac joint and the resultant force of the tensor fasciae latae and the anterior part of gluteus medius (T). The apex of the triangle is at the centre of rotation of the hip. The tensor fasciae latae is at an advantage to counterbalance the body weight (W) by exerting a force at an equal lever arm length. (See text for description.)

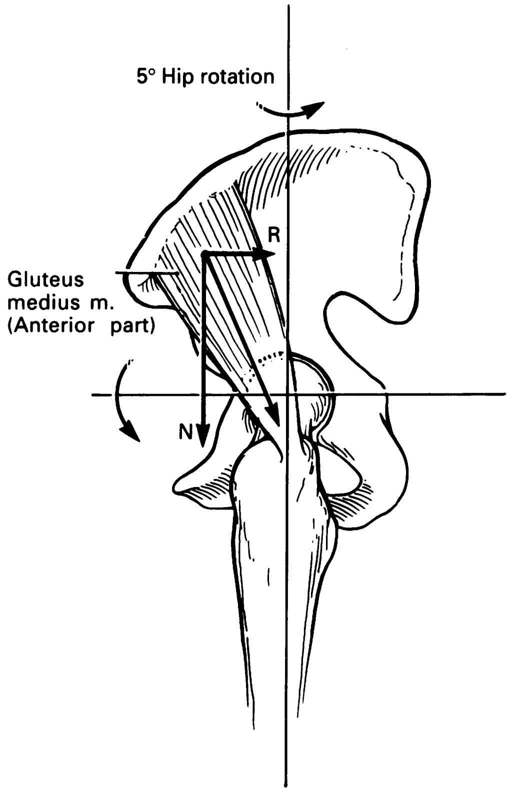

Fig. 8. Lateral projection of the anterior part of gluteus medius. The force exerted by this part has a vertical component (N) which assists in holding the pelvis level, while the horizontal component (R) exerts a rotational moment producing a 5-degree pelvic rotation.

latae and the anterior part of the gluteus medius (abductor force vector) at one corner (T), the weight force vector in the opposite corner (W), with the centre of rotation of the femoral head as the apex of the triangle. The force diagram depicted in Figure 7 illustrates the mechanical advantage of the tensor fasciae latae in holding the pelvis level, because the lever arm lengths of force T and force W are equal.

In a typical gait cycle the abduction function starts immediately after the end of the initial double support phase of the weight-bearing foot. Due to the geometrical position of the femur and the hip, abduction is initiated by the middle part of the gluteus medius. As the transition to midstance takes place, the tensor fasciae latae is situated in an advantageous position to effect and continue the abduction process and it is at this point that it shows the most intense EMG activity. In this position, the anterior part of the gluteus medius will apply a force that has a rotational component that will effect the pelvic rotation (Fig. 8). During the weight-transfer phase of gait, the hip joint is stabilised by the force of the posterior part of the gluteus medius from heel strike to full stance and the force of the gluteus minimus during the full stance and terminal double support.

An analogy can be drawn with the muscle function around the shoulder where the supraspinatus stabilises the humeral head and the deltoid flexes, abducts or extends the arm.

Mechanically, the gluteus medius and minimus are at a major disadvantage to act as the primary hip abductors, whereas the tensor fasciae latae is at a major advantage to exert the necessary force to counterbalance the force of weight during the full stance phase of the gait cycle (Kaplan, 1958; Markhede & Steves, 1981). Evans (1979) stated that the iliotibial tract helps the gluteal abductors prevent the Trendelenburg gait and quotes a case of release of the iliotibial tract for trochanteric bursitis, which resulted in a positive Trendelenburg gait and sign. Furthermore, results obtained with the long-tried Ober test for an abduction contracture of the fasciae latae are additional proof that the major hip abductor is the tensor fasciae latae.

By resolving the line of action of the gluteus medius into three resultant forces, we have obtained a more accurate picture of this muscle's action. The gluteus medius and minimus stabilise the hip during the weight-bearing phase of the gait cycle and act as pelvic rotators to rotate the opposite side of the pelvis forward and to be energy efficient for the swing through phase of gait. The Trendelenburg test relies on weakness of the glutei and the sagging of the pelvis on the sound side occurs because the femoral head cannot be held stable in the acetabulum. The geometry and positioning of the tensor fasciae latae does not allow it to hold the pelvis and stop it from tilting when it is still able to rotate on the unstable femoral head.

The reason for the better clinical results obtained from trochanteric displacement (Stevens & Coleman, 1985) and valgus osteotomies are that these procedures help to stabilise the hip more efficiently and restore pelvic rotation, which is one of the important determinants of normal gait.

SUMMARY

The more accurate description of the anatomy of the glutei and the new biomechanical theory that has been presented describe the abductor mechanism as a system in which the tensor fasciae latae has the primary function of balancing the weight of the body and the non-weight-bearing leg during walking. Gluteus medius with its three parts and phasic functions is responsible for the stabilisation of the hip joint in the initial phase of the gait cycle. It is important also in initiating the major gait determinant of pelvic rotation. Gluteus minimus functions as a primary hip stabiliser during the mid- and late phase of the gait cycle.

This project was supported by BRSG S07 RR 05426–24 awarded by the Biomedical Research Support Grant Program, Division of Research Resources, National Institute of Health.

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