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The biomechanics of trans-femoral amputation

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Abstract

The biomechanics of trans-femoral amputations has not been previously described. Little attention has been paid to the importance of adductor magnus in holding the femur in its normal anatomical axis. Loss of function of adductor magnus leads to abduction of the residual femur, in a trans-femoral amputation. A cadaver study of the adductor group of thigh muscles has been done and the biomechanical importance of these muscles is documented. The moment arms of the three adductor muscles have been determined, based on muscle attachments and muscle size, relative to each other. Adductor magnus has a major mechanical advantage in holding the thigh in its normal anatomical position. Loss of the distal third of its attachment results in a 70% loss of the effective moment arm of the muscle, which contributes to the abducted femur in standard trans-femoral amputations. A muscle preserving trans-femoral amputation, which keeps adductor magnus intact, prevents abduction of the residual femur and may allow for easier walking with a prosthesis. The conflicting reports about adductor magnus activity during the gait cycle can be explained by this muscle's dual innervation by the sciatic and obturator nerves and its dual function as a hip adductor and extensor.

Introduction

The introduction of new socket shapes and designs for trans-femoral amputation has led to a resurgence of interest in trans-femoral amputees. Originally it was thought that by changing socket shape and alignment the residual femur of a trans-femoral amputation could be better controlled within the socket and thus improve the patients gait and functional activity (Long, 1985; Sabolich, 1985.) Several publications have documented that patients with trans-femoral amputations have an increased energy expenditure for walking[1] and that the older patient with little or no physical reserve may lose the ability to walk again (Gonzalez *et al.*, 1974; James 1973; Volpicelli *et al.*, 1985; Waters *et al.*, 1976). Long (1985) noted that the trans-femoral amputee wearing a quadrilateral type socket had an abducted residual femur. The development of the normal shape normal alignment type socket was thought to improve the position of the femoral shaft from an abducted position to a more neutral position. Sabolich (1985) developed the concept of an ischial containment socket with a narrow medial lateral configuration in an attempt to bring the femur back towards adduction and improve the patient's gait and activity. No objective results were provided to show that mechanically this was achieved. A subsequent study comparing patients who used quadrilateral sockets and those that used ischial containment sockets showed that socket shape and design was not able to influence or control the position of the femur within the socket itself (Gottschalk *et al.*, 1989[2]). Alignment of the prosthesis did not appear to influence the position of the residual femoral shaft either.

Little consideration has been given to improving the surgical technique and most of

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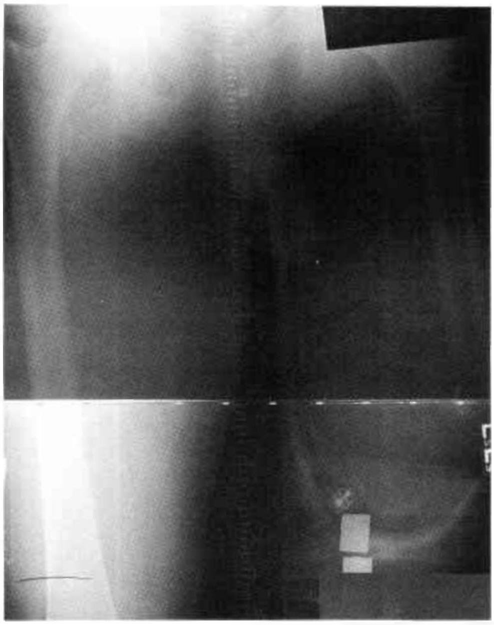

Fig 1. Radiograph of residual femur in prosthetic socket, with femur in abducted position. Increased soft tissue is noted medially.

the surgical literature related to trans-femoral amputations highlights patient function and longevity rather than the surgical technique itself. The standard texts on the technique of trans-femoral amputation make no mention of the adductor muscles and their importance in controlling the position of the femur (Bohne, 1987; Harris, 1981; Burgess, 1989). With a conventional trans-femoral amputation it has been noted that the femur comes to lie in abduction, with a large medial soft tissue mass (Fig. 1). The deviation from the normal mechanical axis of the limb results from the surgery and loss of muscle tissue and muscle attachment as well as the position of the thigh at the time of wound closure (Murdoch *et al.*, 1992).

The paper presents the biomechanics of the adductor muscles of the thigh and the importance of a muscle preserving surgical technique to hold the femur in its normal mechanical alignment.

Materials and methods

A biomechanical model of the adductors of the thigh was developed from the anatomical descriptions in standard texts and cadaver dissections. Four cadavers were dissected and the attachments and volume of each of the adductor muscles was noted. The femur and thigh were divided into thirds to correspond to the attachments of the three major adductor muscles and diagrams based on those used by Brash (1955) were developed to project lines of action of the muscles and the vertical and horizontal resultant forces

A muscle preserving trans-femoral amputation, with myodesis of the adductor magnus and quadriceps has been done on 30 patients. The adductor muscle is preserved intact with its blood and nerve supply and reattached to the distal lateral aspect of the residual femur by a myodesis (Gottschalk, 1992) (Fig. 2). The femur is transected at the appropriate level prior to anchoring of the adductor magnus. At the time of suturing the muscle to the bone, the femur is held in maximum adduction. The quadriceps is also anchored to the femur via anterior and posterior drill holes. Standing radiographs of the residual

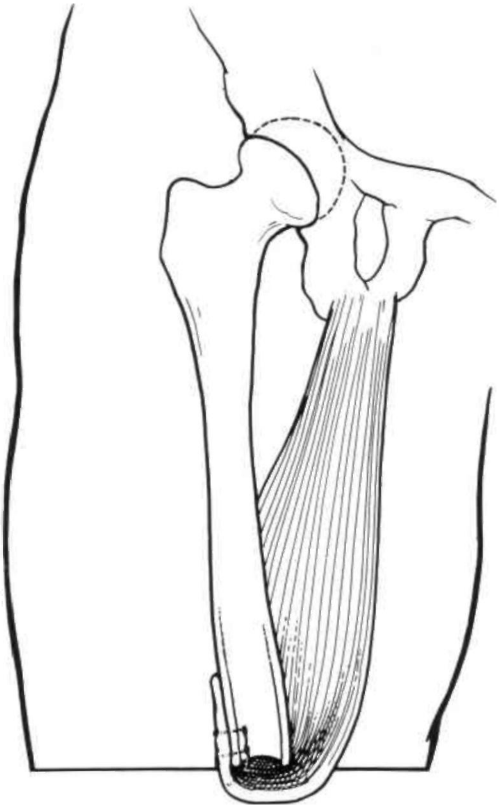

Fig 2. Diagrammatic representation of muscle preserving adductor myodesis for trans-femoral amputation. (Reprinted with permission. Gottschalk, Mosby, 1992.)

femur are taken with and without the socket.

Results

The adductor magnus because of the greater length of its lever arm is best placed to hold the femur in a normal adducted position. Figure 3 shows the normal mechanical and anatomical alignment of the lower limb. The directions of the forces exerted by the adductor muscles are show in Figure 4. The directions of the components of force normal to the lines joining the points of attachment of the muscles and the centre of rotation of the hip joint are also shown. These are the components producing adduction. Adductor magnus is an important adductor because of its bulk and consequent capacity for force development. The cadaver study showed that adductor magnus is three to four times larger in physiological cross-sectional area and volume than the adductor longus and brevis. The point of application of

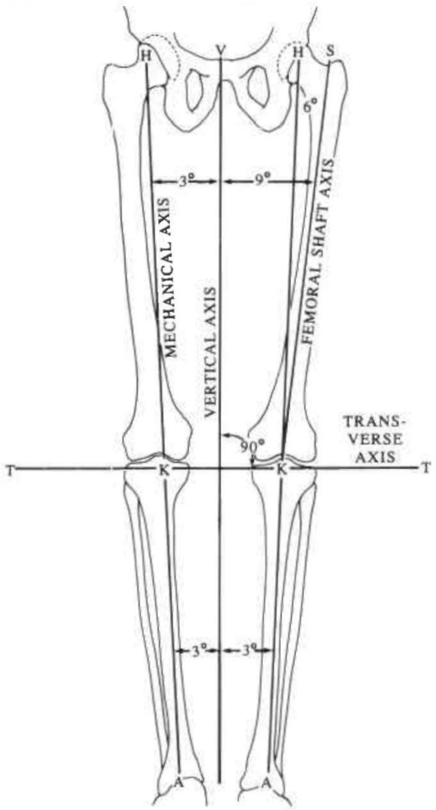

Fig 3. Normal mechanical and anatomical alignment of the lower limb. (Reprinted with permission. Gottschalk *et al.*, J Prosthet Orthot, 1989.)

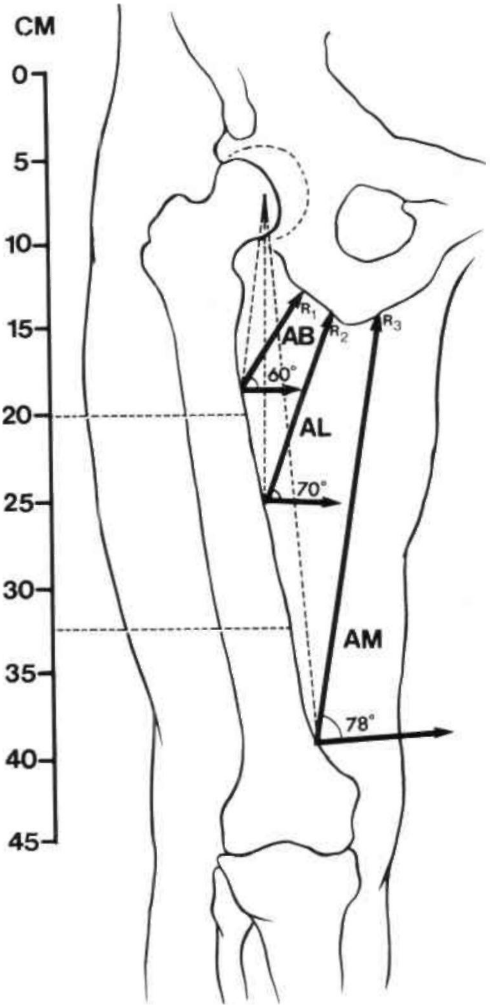

Fig 4. The resultant forces of the adductor group of muscles showing the components producing adduction. The moment arms are depicted by the interrupted line. (AM=adductor magnus, AL=adductor longus, AB=adductor brevis.) (Reprinted with permission. Gottschalk *et al.*, J Prosthet Orthot, 1989.)

the force of the muscles was taken as the middle of the attachment to the femur of each muscle. The unique anatomy of adductor magnus provides the muscle with 2 nerve innervations and 2 separate functions. The most medial portion of adductor magnus makes the greatest contributions to the adduction moment (rotational moment) which is 4 to 5 times that of adductor longus and adductor brevis. Adductor longus and brevis contribute in smaller amounts to normal thigh adduction as noted from the resultant forces. Based on the

Fig 5. Position of the femur after trans-femoral amputation and muscle preserving adductor myodesis.

contribution of each adductor moment, if the distal third of the femur is amputated and an inadequate myodesis of adductor magnus is done, then 70% of the adduction moment is lost. Thus the intact adductor longus and brevis would provide the only mechanism for holding the femur in adduction.

The full surgical procedure has been described in a previous publication (Gottschalk, 1992). The surgical technique to preserve the adductor magnus and re-anchor it adequately to the residual femur by suturing to the lateral distal femur maintains the normal femoral anatomical alignment (Fig. 5). The radiographs show that the anatomical axis and the overall mechanical alignment of the limb can be maintained (Fig. 6). The femur is contained in the middle of the muscle envelope of the thigh, which is a normal adducted position.

Discussion

It is well accepted that the patients with trans-femoral amputations have a higher level of energy expenditure for normal walking, because of loss of the knee joint. One of the contributing factors to abnormal gait in trans-femoral amputees is the mechanical disadvantage of an abducted position of the residual femur, which forces the patient to walk with an increased energy expenditure, despite satisfactory fitting with a prosthesis. Many patients who are good prosthetic users develop pain and discomfort at the distal lateral end of the femur, in the socket, as a direct result of the abducted position. The adductor roll that is commonly noted in trans-femoral amputees is another cause of the patient walking with the leg abducted. The muscle preserving adductor myodesis appears to prevent the formation of an adductor roll, and thereby allow for a more comfortable fitting socket. By applying the biomechanics of the adductor muscles of the thigh and improving the surgical technique to hold the femur in adduction, a patient who may have been a marginal prosthetic user could become a

Fig 6. Radiographs of trans-femoral amputation with muscle preserving adductor myodesis in prosthetic socket, with residual femur in normal anatomical alignment.

definitive prosthetic user. James (1973) noted that patients with a standard trans-femoral amputation had decreased muscle strength as a result of reduced muscle mass, inadequate fixation and atrophy of the thigh muscles. This was confirmed in a study on the neurophysiology of muscle function in the stump (Thiele *et al.*, 1973). It is possible to preserve a large amount of the adductor power by preserving muscle bulk and attaching the distal end of the muscle to the distal end of the residual femur, with the stump held in an over corrected position. This helps maintain the length and tension of the muscle and keeps enough muscle power to overcome the shorter horizontal moment arm. In addition, the femur is no longer in an abducted position and this allows the abductor mechanism to function normally.

The hip abductor mechanism remains intact at the time of a trans-femoral amputation. Gluteus medius, minimus and parts of maximus are abductors of the hip. However tensor fasciae latae plays the most important role in hip abduction during the stance phase of gait (Gottschalk *et al.*, 1989[1]). Although the very distal attachment of tensor fasciae latae is lost in a trans-femoral amputation, the muscle can still function as a thigh abductor because of its indirect attachment from the fascia lata to the linea aspera via the lateral intermuscular septum. However, at the time of surgery the tensor fasciae latae should be sutured to the medial fascia of the thigh to provide additional stabilisation. Failure to re-anchor the tensor fasciae latae may contribute to some weakness of the hip abductor mechanism. Interference with the action of adductor magnus leads to an imbalance of the mostly intact abductor mechanism with subsequent abduction of the femur. Keeping adductor magnus intact and adequately re-anchoring it to the residual femur will maintain the balance between the hip abductors and adductors. It is not possible to hold the residual femur adducted with a prosthetic socket irrespective of its shape or design, as has previously been reported (Gottschalk *et al.*, 1989[2]), since the femur cannot be displaced in its soft tissue envelope.

Electromyographic studies of adductor magnus provide conflicting information. Review of the literature reveals that most likely the muscle is active at the beginning of stance phase and again at the end of stance and into early swing phase (Green and Morris, 1970; Inman *et al.*, 1981). Because of the muscle's dual innervation by the sciatic and obturator nerves, most likely different parts of the muscle are active at different times during the gait cycle. Inman et al., (1981) note that adductor magnus is active only at the beginning and termination of swing phase. Green and Morris (1970) describe activity of adductor magnus and lognus and noted that activity occurred in stance phase. The disparity in the results is most likely due to the dual innervation of adductor magnus and its dual function of hip extensor and thigh adductor.

In a distal third femur amputation the tendon of the adductor magnus should be preserved and swung around the distal end of the femur and anchored by drill holes to the lateral femur, with the femur maximally adducted. This preserves maximum muscle force by having an intact adductor system, and provides a mechanical advantage for the adductors and abductors of the thigh. In a middle third amputation, instead of transecting adductor magnus, it should be detached from the bone and swung around the distal end of the adducted femur. The myodesis can then be performed and redundant tissue excised.

Those patients who have had the amputation as described above have the residual femur in a normal, or near normal anatomical alignment. (Fig. 6). The position of the femur is not influenced by a prosthetic socket. In a standard trans-femoral amputation the position of the femur may vary from 6° of adduction to 14° of abduction irrespective of the type of prosthetic socket that is used (Gottschalk *et al.*, 1989[2]). The normal anatomical position of the femur is 7-10° of adduction. The mechanical axis of the lower limb is a line from the centre of the hip through the middle of the knee and ankle. This was first described by Duchenne in 1867 (Duchenne, 1949) and has been well established in orthopaedic surgery, especially total knee replacement (Freeman, 1980; Hungerford *et al.*, 1984; Maquet, 1980). Thus, a trans-femoral amputation which maintains the anatomical alignment of the residual femur will have a mechanical alignment when a prosthesis is fitted similar to that of a normal intact limb. The combination of a normal mechanical alignment and maintenance of the muscle moment arm should improve the patient's ability to walk.

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