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IN VIVO MOMENT ARM LENGTHS FOR HIP EXTENSOR MUSCLES AT DIFFERENT ANGLES OF HIP FLEXION

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Abstract—Moment arm lengths of three hip extensor muscles, the gluteus maximus, the hamstrings and the adductor magnus, were determined at hip flexion angles from 0° to 90° by combining data from ten autopsy specimens and from twenty patients, the latter examined by computed tomography. A straight-line muscle model for muscle force was used for the hamstrings and adductor magnus, and for the gluteus maximus a two-segment straight-line muscle force model was used. With the joint in its anatomical position the moment arm of the gluteus maximus to the bilateral motion axis averaged 79 mm, for the hamstrings 61 mm and for the adductor magnus 15 mm. The moment arm of gluteus maximus decreased with increasing hip flexion angle. The hamstrings showed an increase in moment arm length up to an average of 35° hip flexion and then a decrease with increasing hip flexion angle. The corresponding figures for the adductor magnus moment arm showed an increase up to 75° and then a decrease. Statistical analysis revealed significant differences in moment arm length between men and women.

INTRODUCTION

Quantitative anatomical data are required for the biomechanical investigation of hip joint forces, as pointed out by several authors, for example Dostal and Andrews (1981), Johnston (1973) and Reynolds and Hubbard (1980).

Earlier published works include that of Eycleshymer and Schoemaker (1905), which is often used for measurement of basic anatomical structures. Their atlas contains reconstruction drawings, of about four-fifths natural size, from transverse sections of different cadavers. Dostal and Andrews (1981) used the straight-line muscle model between the origin and insertion of hip muscle attachment points on a male dry bone specimen. Using anatomical descriptions in text books as a guide, points representing muscle attachments were marked on the specimen and coordinates were measured in a laboratory reference frame. The three-dimensional muscular anatomy was then described. Jensen and co-workers (Jensen and Davy, 1975; Jensen and Metcalf, 1975) used two cadaver specimens to quantify the centroid line, representing midpoints of several sections of some hip abductor and flexor muscles. McLeish and Charnley (1970) and Inman (1947) inserted wires through the approximate centre of hip abductor muscles, and Pohtilla (1969) used small radiopaque markers placed in the centre of the tendons of origin and insertion. In the last two studies mentioned conventional roentgenograms were used to measure the muscular moment arms.

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There is no study dealing with the three-dimensional course of the hip muscles obtained *in vivo*. The general aim of the present study was to investigate the three-dimensional location of some hip muscular coordinates required for calculations of moment arm lengths and to calculate these moment arms as a function of hip flexion angle. The following specific questions were addressed:

1. What is the length of the moment arms of the hip extensors (i.e. the gluteus maximus, hamstrings and adductor magnus) to the bilateral hip motion axis with the joint in its anatomical position?
2. Is there a difference in moment arm length between men and women?
3. What is the length of the moment arms at different angles of hip flexion?

METHODS, MATERIALS AND SUBJECTS

Design of the study

Computed tomography gives an accurate anatomical cross-sectional image and, using consecutive slices, a three-dimensional survey allows calculations of muscular moment arms. Even though the course of a muscle can be accurately described by CT, a tendinous origin or insertion of the investigated muscle cannot sometimes be exactly identified since the attenuation does not differ enough from the surrounding tissue. If this is the case, as for the hamstrings and adductor magnus in the present study, data from autopsy specimens provide help: in our work, a skeletal landmark was identified on the specimen and the distance between this landmark and the muscle origin was measured. Since this skeletal landmark was easily identifiable on CT, the muscle origin was obtained on the CT using the measured autopsy distance.

With this background the present study was divided into two parts. First, distances between an anatomical skeletal landmark and muscular origins, necessary for the CT analysis, were determined from autopsy specimens. Secondly, an *in vivo* CT analysis of the pelvis and proximal thigh was performed on patients. All autopsy specimens and subjects were placed supine in the anatomical position (i.e. the body imagined as standing erect with the feet together and toes directed forward) during the measurements. Concerning observer influence on the measurements, repeated independent measurements performed on different occasions showed an intraobserver variation of ± 1 mm, in both CT and specimen studies.

A right-handed orthogonal coordinate system (Fig. 1) with the origin placed at the centre of the femoral head was used. Relative to the anatomical position the x-axis passed horizontally through both femoral heads, the y-axis was vertical running in the cranio-caudal direction and aligned with the femoral link and the z-axis was orthogonal. The x-axis was aligned with the bilateral hip motion axis about which hip flexion and extension movements occur.

A straight-line muscle model for muscle force was used for the hamstrings and adductor magnus. For the gluteus maximus a two-segment straight-line muscle force model was used. The force exerted by each muscle at any point along the centreline of the muscle belly and tendon was represented by a force vector at that point which was tangent to this line. Both the hamstrings and adductor magnus are long muscles running along the femoral shaft. Thus, the hamstrings and the adductor magnus were considered to have a cranio-caudal course parallel to the y-axis in the parasagittal plane passing through the hip centre, regardless of the hip flexion angle.

The autopsy specimen analysis

Ten adult specimens, five male and five female (Table 1), were dissected with respect to the muscles acting about the left hip joint. The specimens were measured manually to the nearest millimetre using a millimetre-gauge.

The locations of the origins (circles in Fig. 2) of the hamstrings and the adductor magnus muscles were determined in relation to a point on the inferior ramus pubis which was most caudal when the hip was in the anatomical position. This skeletal landmark was referred to as the reference point (filled triangle, Fig. 2). The

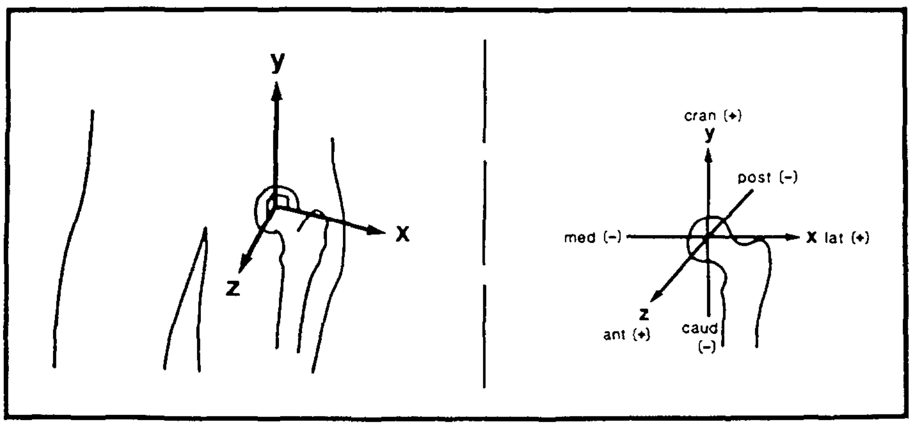


Fig. 1. Anterior view of left hip joint showing the right-handed orthogonal coordinate system used. Origin was placed at the centre of left femoral head. Relative to the anatomical position the y-axis was vertical (running in the cranio-caudal direction) and aligned with the femoral link, and the z-axis was orthogonal. Coordinate system to the right visualizes the signification of the + and − signs in Table 2.

Table 1. Specimen ($n = 10$) and subject ($n = 20$) data (mean $\pm$S.D.)

	Height (m)		Weight (N)		Age (yr)	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
Specimens						
Males	1.76	(0.04)	—	—	78	(1)
Females	1.60	(0.05)	—	—	82	(4)
All	1.68	(0.06)	—	—	80	(3)
Subjects						
Men	1.76	(0.02)	736	(39)	70	(3)
Women	1.66	(0.02)	589	(39)	63	(7)
All	1.71	(0.03)	667	(59)	67	(6)

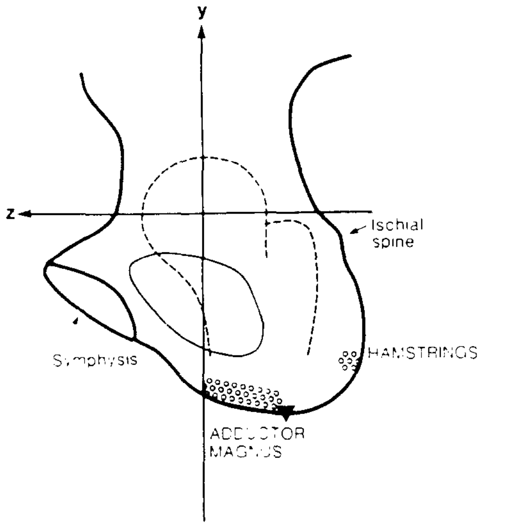


Fig. 2. Medial view of pelvis sectioned in mid-sagittal plane. Filled triangle indicates reference point, i.e. the point on the inferior ramus pubis which was most caudal when the hip joint was in the anatomical position. Areas with circles indicate muscular origins. The coordinate system is aligned with that in Fig. 1.

vertical distance (y-distance, Fig. 2) between the origin of the hamstrings and the reference point was measured, and the average was used in the CT analysis described below. In the adductor magnus, the antero-posterior distance (z-distance, Fig. 2) was measured, firstly between the reference point and the anterior border of the origin and secondly between the reference point and the posterior border. From these values the midpoint of the origin was determined. The average antero-posterior distance between midpoint and reference point was used in the CT analysis.

The CT analysis

Twenty patients, ten men and ten women, were analysed (Table 1). The subjects were informed about the present study and volunteered to participate. The study was also approved by the Karolinska Institute ethical committee. All subjects had carcinomas, but none had neoplasms affecting the structures to be analysed, and all were active in daily life. The CT examination was primarily diagnostic, but to make the present study possible some extra slice images were taken. The additional x-ray dose (1.5 mGy) was negligible, especially since all subjects were to receive radiotherapy to the pelvic area due to the neoplasm.

All examinations were performed on a General Electric CT/T 7800 scanner with a 320 by 320 matrix and 10 mm collimator (giving slices of 10 mm thickness). The patients were placed supine in the anatomical position and consecutive scans throughout the lower back, pelvis and proximal thigh were made. The x, y, z coordinates of relevant points (described below) were determined electronically using a movable cursor on the CT monitor. The coordinates were recorded in millimetres, the centre of left femoral head being defined as coordinate system origin ($x, y, z = 0, 0, 0$) (Fig. 1). As seen in Fig. 1 the y-coordinate represents the cranio-caudal level of the CT-slice, and the x, z-coordinates represent a point in the transverse plane at that y-level. Figure 3 illustrates the level of the specific analysed transverse axial images shown in Fig. 4.

The proximal and distal borders of the gluteus maximus origin were visible on the CT image. To determine the midpoint of the gluteus maximus origin, the levels (i.e. y-coordinates) of the gluteus maximus proximal and distal borders were identified on consecutive CT images. From the y-coordinates of these two slices, the level of the midpoint was calculated (A in Fig. 3). This midpoint level was displayed on the CT monitor and the coordinates of the origin were determined (cross in Fig. 4a).

Next, the insertion of the gluteus maximus was determined. The muscle inserts on the gluteal tuberosity on the posterior proximal femur shaft, and its most superficial muscular parts in the ilio-tibial tract (Hollinshead, 1958). To determine the midpoint level of the insertion it was necessary to identify the proximal and distal borders of its insertion. However, no distinct proximal border of the femoral insertion could be defined in the specimen study or in the CT-images. In anatomical text books, the proximal border of the insertion is generally placed at the lesser trochanter level (Grant, 1972; Hollinshead, 1958; Sobotta and Becher, 1975). Therefore, the proximal border of the insertion was defined as being at the level of the distal border of the lesser trochanter, and this border is easily identifiable on the CT axial images. The level (y-coordinate) of this CT image was recorded. The distal border of the gluteus maximus insertion was then determined. The CT-slice showing the most distal part of the gluteus maximus muscle belly was displayed. The tendinous insertion was considered to be within the displayed slice because the muscle has an oblique course and the final tendinous part is very short. Thus the level (y-coordinate) of the displayed image was determined. Then, from the known y-coordinates of the proximal and distal borders, the level of the midpoint was calculated (B in Fig. 3). The CT-slice of this midpoint level was displayed and the insertion coordinates determined (cross in Fig. 4b).

Since the gluteus maximus muscle impinges upon the underlying skeleton during hip flexion (Dostal and Andrews, 1981), we recorded the level (y-coordinate) of the most *dorsal* part of the ischial bone (C in Fig. 3). At that level the x, z-coordinates of a point representing the middle of the muscle belly were determined (Fig. 4c).

As mentioned above, the hamstring origin was not visible on the CT image. However, from the specimen study it was known that the mean origin of the hamstrings was located 19 mm cranially to the reference point (y-distance in Fig. 2). The y-level points correspond to the y-coordinates describing the level of the CT-slices. Therefore the slice at the level of the reference point was displayed (D in Fig. 3 and Fig. 4d) and its y-coordinate recorded. Then, referring to the specimen study, the slice 20 mm cranially to the reference point was displayed (E in Fig. 3) and the x, z-coordinates of the hamstring origin (cross in Fig. 4e) were determined.

To determine the adductor magnus origin (not visible on the CT image because it is partly tendinous and not surrounded by fat), the CT-slice at the level of the reference point was displayed again (Fig. 4d). With the use of specimen data the mean antero-posterior distance (z-distance in Fig. 2) between the reference point and the midpoint of the adductor magnus origin was marked in the CT-slice (arrow in Fig. 4d). The coordinates of the midpoint were then determined in the CT-slice where the z-coordinate of the origin of the adductor magnus intersected the inferior ramus pubis (cross in Fig. 4d).

For the statistical analysis of significant differences between means, Student's t-test with pooled variance was used.

RESULTS AND ANALYSIS

The specimens

Figure 2 shows the locations of the origins (circles) of the hamstrings and adductor magnus in relation to the reference point (filled triangle). The mean vertical distance (y-distance in Fig. 2) between the reference point and the origin of the hamstrings was 19 mm (male 21 mm, range 10–30, and female 17 mm, range 10–30). The average antero-posterior distance (z-distance in Fig. 2) from the reference point to the anterior border of the origin of the adductor magnus was 51 mm (range 40–60) for the male specimens and 23 mm (range 10–40) for the female. In all the male specimens the posterior border of the adductor magnus origin was located at the reference point. The same posterior border in the female specimens was located at a point 2 mm (mean) anterior to the reference point. The midpoint of the origin of the adductor magnus was determined to a point 26 mm anterior to the reference point for the males and 14 mm anterior to the reference point for the females.

The subjects

The averaged values of the investigated muscular coordinates, determined by CT, are given in Table 2 (the significance of the + and − signs in Table 2 is defined to the right in Fig. 1). The coordinates in the parasagittal (y, z)-plane are also shown in Fig. 5. In relation to the bilateral hip axis the origin of the hamstrings was more posteriorly located in the men (64 mm) than in the women (58 mm) ($p < 0.001$). However, the opposite was found concerning the origin of the adductor magnus, which was more posterior in the women than in the men: 19 mm and 10 mm respectively ($p < 0.01$). Since the variation in the z location of the adductor magnus origin was 51 mm in men, 16 mm (31%) of the origin, on average, was located anterior to the bilateral hip motion axis. In the female subjects, the entire origin of adductor magnus was located posterior to the motion axis in the anatomical hip position.

Analysis of subjects' muscular moment arms

The gluteus maximus (broken line, Fig. 5) touches the posterior aspect of the tuber ossis ischii (y_1, z_1), makes a small bend when passing this connection to the pelvis and runs further to its femoral insertion (y_2, z_2). The midpoint of the muscle belly when passing the tuber ossis ischii is also shown in Fig. 4c. The three-dimensional muscle force vector and the projection of the force vector on the (y, z)-plane define a further plane. This plane is perpendicular to the sagittal plane as is the orthogonal axis running through the moment

Table 2. The averaged muscular coordinates (mm ± S.D.) in the subjects as determined by CT. Coordinate system origin is aligned with the centre of the left femoral head. The significance of the + and − signs is visualized to the right in Fig. 1

		Men (n = 10)		Women (n = 10)		All subjects	
		Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
Gluteus maximus	x_0	−53	(5)	−63	(4)	−58	(5)
(pelvic origin)	y_0	+63	(4)	+68	(5)	+66	(5)
	z_0	−96	(4)	−93	(2)	−94	(3)
Gluteus maximus	x_1	−1	(3)	+2	(2)	+1	(3)
(tuber ischii	y_1	−37	(4)	−37	(4)	−37	(4)
level)	z_1	−74	(2)	−68	(3)	−71	(3)
Gluteus maximus	x_2	+32	(3)	+31	(3)	+32	(3)
(femoral	y_2	−102	(4)	−94	(3)	−98	(4)
insertion)	z_2	−28	(3)	−23	(4)	−25	(4)
Hamstrings	x_3	−34	(3)	−22	(4)	−29	(4)
(pelvic	y_3	−48	(3)	−40	(2)	−44	(3)
origin)	z_3	−64	(1)	−58	(2)	−61	(2)
Adductor magnus	x_4	−63	(3)	−49	(4)	−56	(4)
(pelvic	y_4	−61	(3)	−57	(3)	−59	(3)
origin)	z_4	−10	(2)	−19	(3)	−15	(3)

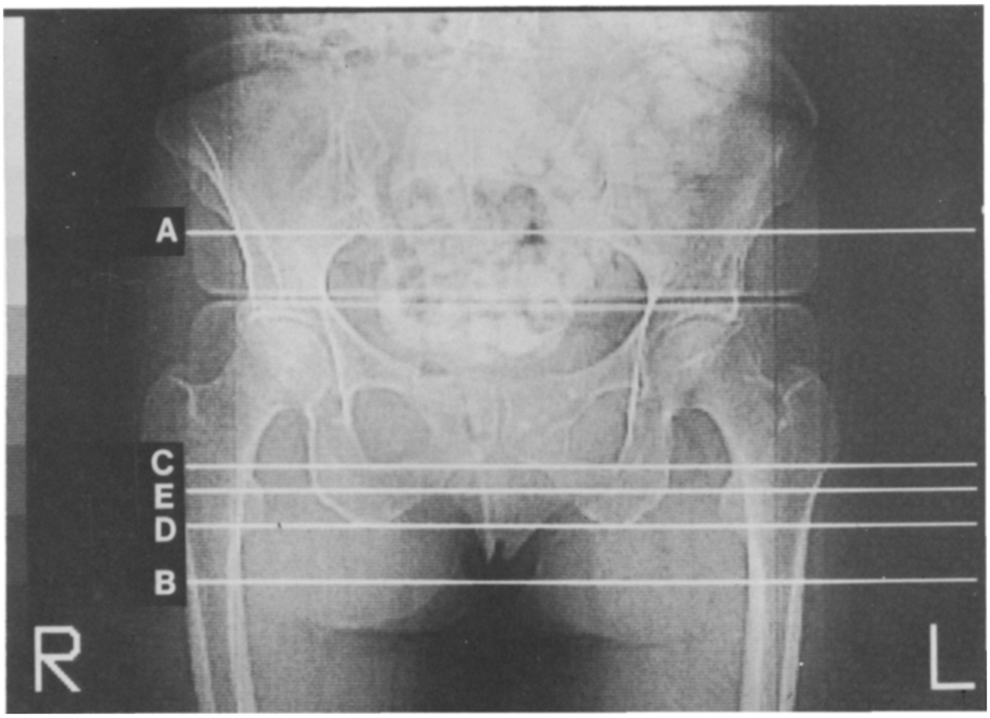


Fig. 3. CT in ScoutView mode, giving survey picture from one subject to illustrate level of specific analysed transverse axial images shown in Fig. 4. A indicates level of midpoint of gluteus maximus origin (corresponding to Fig. 4a) and B midpoint of its femoral insertion (corresponding to Fig. 4b). C is level of most dorsal part of ischial bone (corresponding to Fig. 4c). D is level of reference point (corresponding to Fig. 4d). E is level of hamstring origin (corresponding to Fig. 4e).

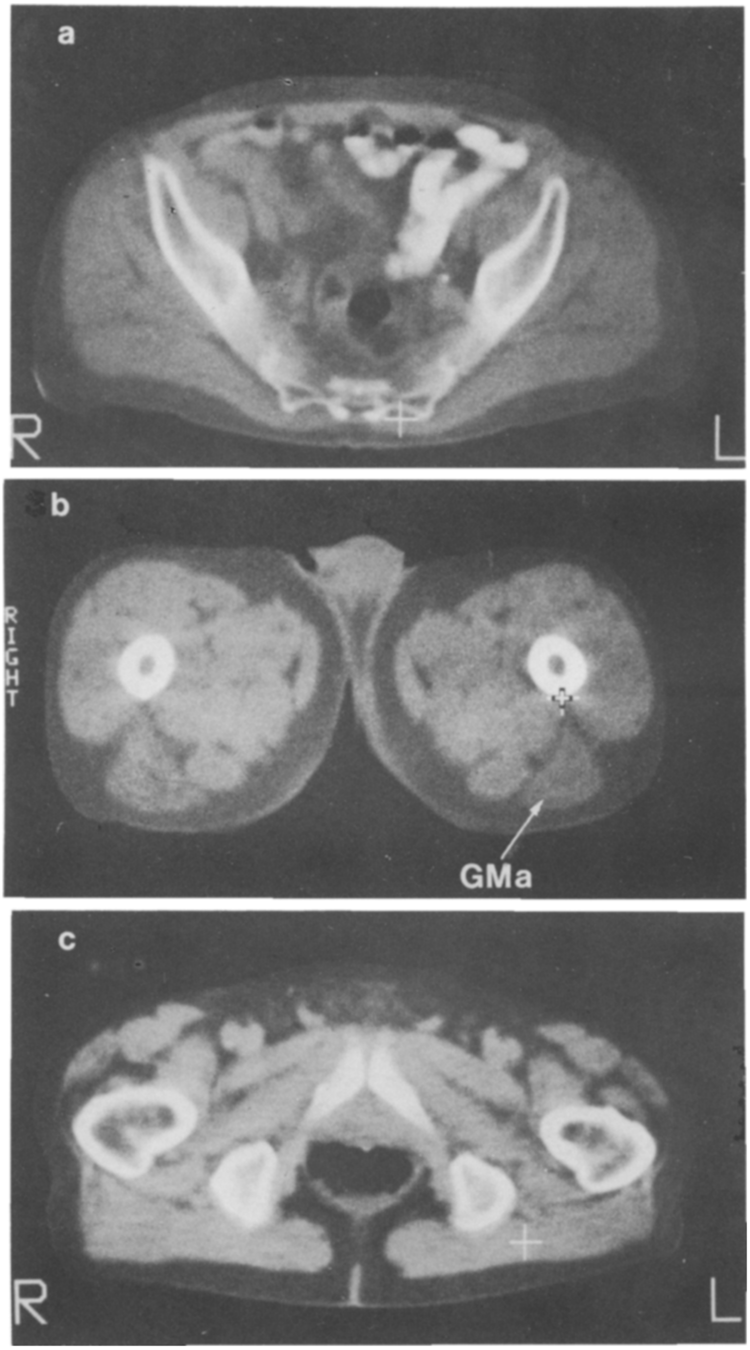
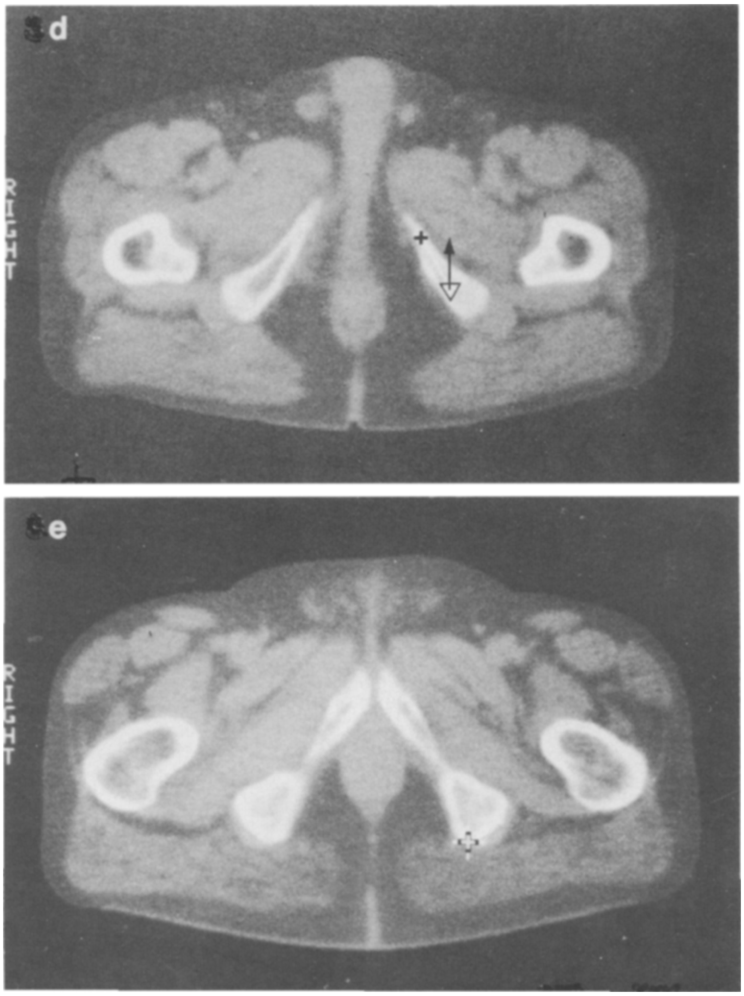


Fig. 4. Transverse CT scans at different levels. Determined coordinates are indicated with crosses. (a) Midpoint of gluteus maximus origin (A-level in Fig. 3). (b) Midpoint of gluteus maximus femoral insertion (B-level in Fig. 3), GMa is gluteus maximus muscle belly. (c) Midpoint of gluteus maximus muscle belly (C-level in Fig. 3).



.. 4. (d) Midpoint of origin of adductor magnus (cross) (D-level in Fig. 3), triangle is reference po
(e) Hamstring origin (E-level in Fig. 3).

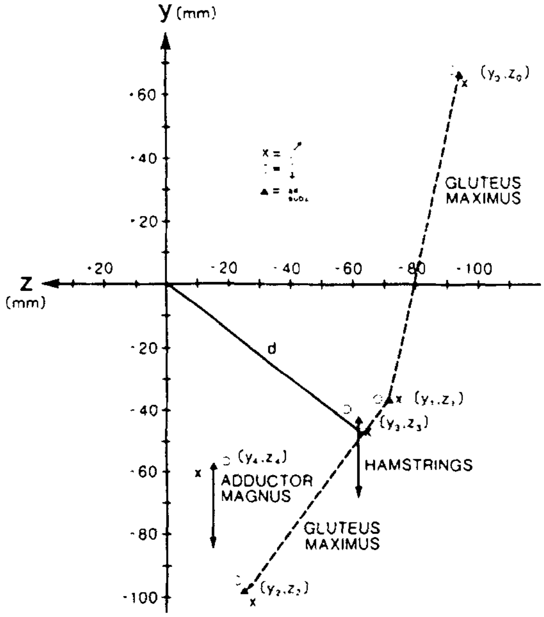


Fig. 5. Coordinate system showing a parasagittal plane through left femoral head. Crosses indicate determined coordinates in ten men, circles in ten women and filled triangles all subjects. Broken line indicates course of gluteus maximus muscle and d its moment arm. The coordinate system is aligned with that in Fig. 1 and the y- and z-coordinates correspond to Table 2.

centre 0. Thus the perpendicular distance between the projection of the force vector on the (y, z)-plane and the origin 0 is equal to the perpendicular distance between the force vector and the x-axis. Therefore the gluteus maximus moment arm (d, Fig. 5), defined as the perpendicular distance between the muscle force vector line-of-action and the bilateral motion axis is given by

$$|d| = \left[\sin\left(\arctan\left|\frac{z_2 - z_1}{y_2 - y_1}\right|\right)\right]\left[|y_2| - \left(\left|\frac{y_2 - y_1}{z_2 - z_1}\right| z_2\right)\right] \quad (1)$$

where x, y, z are coordinates given in Table 2 with the joint in its anatomical position. The length of the calculated moment arm of gluteus maximus is shown in Table 3. The men had significantly longer moment arms than the women had ($p < 0.05$).

During hip flexion the pelvis rotates about the bilateral hip motion axis, causing the muscular z-coordinates (z_a) to change as sine functions and the y-coordinates as cosine functions of the hip flexion angle (A_{hip})

$$z_a = \sqrt{z^2 + y^2}\,\sin\left[\arctan\left(\frac{z}{y}\right) + A_{hip}\right] \quad (2)$$

$$y_a = \sqrt{z^2 + y^2}\,\cos\left[\arctan\left(\frac{z}{y}\right) + A_{hip}\right]. \quad (3)$$

To calculate the gluteus maximus moment arm at different angles of hip flexion the coordinates calculated from equation (2) were used in equation (1). The length of the moment arm at different angles of hip flexion is shown numerically in Table 4 and graphically in Fig. 6.

The z coordinates of the origins of the hamstrings (z_3) and adductor magnus (z_4) are shown in Table 2 and Fig. 5 and represent the muscular moment arm to the bilateral motion axis with the hip joint in its anatomical position. The lengths of the moment arms are shown in Table 3. The difference in length between the men and the women was highly significant.

The changed moment arms (i.e. z_3- and z_4-coordinates) for the hamstrings and adductor magnus at different angles of hip flexion were calculated using equation (2). The lengths of the moment arms are shown in Table 4 and Fig. 6.

To determine whether a linear relationship existed between height and moment arm length the correlation coefficient was calculated for each muscle. The result was 0.39 for the gluteus maximus, 0.66 for the hamstrings and 0.52 for the adductor magnus.

DISCUSSION

The purpose of the present study was to analyse the moment arms of hip extensor muscles which act in the sagittal plane. Thus we calculated the moment arm to the moment axis perpendicular to the sagittal plane (i.e. the bilateral hip axis). We are of course aware that especially the gluteus maximus also acts with respect to the antero-posterior axis (about which hip abduction and adduction occur). However, we did not calculate this moment arm because in such a model other major

Table 3. Moment arm length (mm ± S.D.) of the hip extensor muscles to the bilateral hip motion axis. The joint in its anatomical position

		Gluteus maximus*		Hamstrings‡		Adductor magnus†	
		Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
Men	(n = 10)	82	(3)	64	(1)	10	(2)
Women	(n = 10)	76	(3)	58	(2)	19	(3)
All subjects		79	(3)	61	(2)	15	(3)

Significant differences in length of muscular moment arm between men and women:
* $p < 0.05$.
† $p < 0.01$.
‡ $p < 0.001$.

Table 4. Moment arm length (mm) of the hip extensors to the bilateral hip motion axis with the joint in different flexed positions

	Hip flexion angle (degrees) 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Gluteus maximus																		
Men	81	79	78	76	74	71	69	66	63	61	57	54	51	48	44	41	37	33
Women	75	74	72	70	69	66	64	62	59	56	54	51	48	44	41	38	34	31
Hamstrings																		
Men	68	71	74	77	78	79	80	80	79	78	76	74	71	67	63	58	53	48
Women	61	64	66	68	69	70	70	70	69	68	66	64	61	57	54	49	45	40
Adductor magnus																		
Men	15	20	25	30	35	39	43	47	50	53	56	58	60	61	62	62	62	61
Women	24	29	33	37	41	45	48	51	54	56	58	59	60	60	60	59	58	57

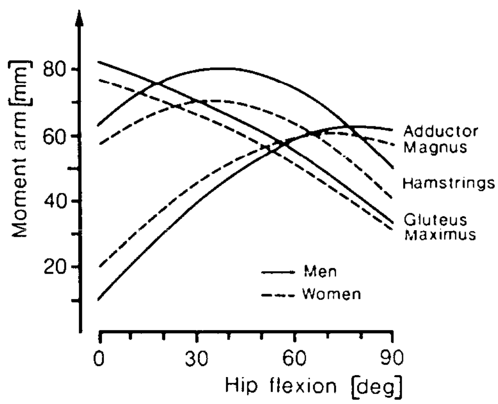


Fig. 6. Graphical illustration of mean moment arm lengths at different hip angles in ten men and ten women.

contributing muscles should be taken into account: the tensor fasciae latae, gluteus medius and gluteus minimus. We have recorded the corresponding three-dimensional data for these muscles as well as for the hip flexor muscles, and manuscripts are in preparation.

A force vector running in the centre of the muscle was taken to represent the muscular force in the present study. Using this assumption the midpoint of the gluteus maximus muscle belly at the tuber ossis ischii level, the midpoint of its insertion and the midpoints of the adductor magnus and hamstring origins were determined. An approximation is always introduced when a vector represents a muscle which spreads out. Since the fibres of the adductor magnus muscle diverge only slightly and symmetrically at the origin, it may be justified to take the determined midpoint to represent the point of application of the muscle force. Muscles such as the gluteus maximus with parallel fibres from their attachments are satisfactorily represented by a force vector, as are the hamstrings which show a well-defined origin.

CT is a non-invasive method permitting three-dimensional measurements. It has been used for anatomical cross-sectional evaluation of skeletal and muscular structures, i.e. the femoral neck anteversion angle (Browning *et al.*, 1982), areas of thigh muscles (Häggmark *et al.*, 1978) and normal anatomy of the hip (Dubowitz *et al.*, 1981). In the present study the thickness of all CT-slices was 10 mm and thus the precision was ± 5 mm in determining the y-coordinates for calculations of the moment arm of the gluteus maximus muscle. Any systematic error of either $+5$ mm or -5 mm in all subjects at the femoral insertion would change the moment arm of the gluteus maximus by ± 0.5 mm. A systematic error of the same order in all subjects in determining the gluteus maximus y-coordinate at the tuber ischii level would change the moment arm ± 2 mm. The accuracy of the moment arm of the hamstrings and adductor magnus is due to the precision in the transverse (y, z)-plane, i.e. 1 mm.

The calculations of moment arm length at different angles of hip flexion were based on the coordinate data in Table 2. The length was then calculated using equation (2) which is based on known geometrical relationships, adding no more bias to the results. Thus the above discussion for the gluteus maximus is also valid for the moment arm length at different flexed positions. During subsequent hip flexion the origin of the hamstrings and adductor magnus moved posteriorly. In our model the muscular course was still assumed to be parallel to the y-axis. This was justified because these muscles are long and the maximum error introduced was calculated not to exceed 1.2 mm on average. It was also assumed that there was no impingement of the muscle line-of-action on surrounding joint structures.

The ages of the subjects participating in the CT-study were high, but the relationship between the anatomical structures does not change in the adult human. Thus the figures reported in the present study may be considered applicable also to young adults. However, marked muscle bulkiness will induce a moment arm lengthening for the gluteus maximus. The moment arm lengths differed significantly between men and women probably due to different pelvic geometry. However, there was low correlation between height and moment arm lengths, although the height of all subjects was well within the normal limits in Sweden for the different sexes respectively.

Two moment arms may be defined for the gluteus maximus. In the present study the perpendicular distance between the distal (caudal) part of the gluteus maximus and the bilateral axis was considered to represent the correct moment arm value (Fig. 5). In our opinion this was adequate because the gluteus maximus is in contact with underlying pelvic structures between its origin and the ischial tuberosity; and these points cannot move in relation to each other. The muscle then leaves its pelvic connection at the tuber ischii and runs straight to its femoral insertion. During hip extension the tuber ischii and the femoral insertion (Fig. 5) move towards each other and that motion occurs about the bilateral hip axis.

The length of the moment arm of the gluteus maximus at 0° hip flexion in the present study (average 79 mm) differs from the 56 mm reported by Pohtilla (1969). In the latter study four cadaver limbs were used. The line-of-action of the muscle was determined by drawing a line on conventional lateral roentgenograms between the muscular origin and insertion. This method is similar to the straight-line muscle model. For curved muscles such as gluteus maximus, as shown in Fig. 5, this technique gives lower values for the length of the moment arm. These differences have been studied by other investigators (Jensen and Davy, 1975).

The adductor magnus moment arm at 0° hip flexion reported in the present study (10 mm in men and 19 mm in women) is shorter than the 30 mm reported by Pohtilla. However, the sex of the cadaver specimens used in Pohtillas' study is not given and the use of conventional roentgenographic technique with less accuracy makes it impossible to discuss the reason for the difference between the results. The hamstring moment arm at 0° hip flexion agrees largely with that reported by Pohtilla and is slightly longer than Dostal and Andrews' finding (1981).

In the present study, about one third of the origin of the adductor magnus was found to be located anterior to the bilateral hip motion axis in male subjects with the joint in its anatomical position. Consequently, the anterior part of the muscle does not act as an extensor of the hip in this position. From equation (2) it was calculated that the whole muscular origin was located posterior to the motion axis at hip angles exceeding 16° flexion, thus making the whole muscle act as a hip extensor at these angles. In women, however, the entire muscle origin is located posterior to the motion axis, making the entire muscle act as a hip extensor throughout the motion sector. These data may explain the difference in maximum hip extensor muscle moment between men and women reported earlier (Németh *et al.*, 1983): in both sexes the highest maximum extensor moments occur at 90° hip flexion, decreasing with decreasing hip angle. However, the maximum muscle moment of women decreases continuously over the motion sector, whereas the moment in male subjects decreases twice as much between 30° and 0°. This is probably because on average 31 % of the adductor magnus origin mechanically becomes a flexor during the last 30° of extension. Since this phenomenon does not occur in women, their extensor muscle moment does not reduce as in men at these joint angles.

In biomechanical analysis of the human locomotor system one limiting factor is the accuracy of quantitative anatomical data. The methods in the present study, combining specimen data and *in vivo* CT-analysis on subjects, represent an attempt to measure and calculate anatomical data which can be used for biomechanical analysis of hip joint load. In one of our recent studies (Németh and Ekholm, in press) data from the present investigation have been used to predict hip compressive load during different lifting tasks.

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