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FUNCTION AFTER REMOVAL OF VARIOUS HIP AND THIGH MUSCLES FOR EXTIRPATION OF TUMORS

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Forty-six patients who had undergone excision of one or more well defined hip and/or thigh muscles because of a soft-tissue tumor or a tumoriform lesion were investigated with respect to the function of the operated limb and the isometric and isokinetic strength of the affected motion or motions, relative to the non-operated side (percentage). *Hip flexion:* Loss of the iliopsoas caused only slight impairment of function. The flexion strength decreased with increasing flexion of the hip joint. Loss of the rectus femoris reduced the isometric strength by 37 and the isokinetic strength by 17 per cent. *Hip abduction:* The strength reduction was only about 50 per cent and the impairment of function only slight or moderate even in patients with extensive loss of abductor muscles. *Hip adduction:* Removal of all three prime adductors (longus, brevis, magnus) caused a strength reduction of about 70 per cent but the impairment of function was only slight or moderate. *Hip extension:* Loss of the gluteus maximus caused only a small strength reduction and no impairment or only slight impairment of function. Significant strength reduction was only seen when all hamstrings had been removed. *Knee extension:* Loss of one, two, and three of the quadriceps muscles reduced the isometric strength by 22, 33, and 55 per cent, respectively. The isokinetic strength was reduced somewhat more. The strength reduction usually had to exceed 50 per cent to cause more than slight impairment of function. *Knee flexion:* Loss of the semitendinosus, the biceps femoris, and all the hamstrings reduced the isometric strength by 24, 28, and 67 per cent, respectively. The isokinetic strength was reduced somewhat less. Loss of one of the hamstrings usually caused no impairment of function whereas loss of all three resulted in moderate impairment of function.

Key words: biomechanics; Cybex II; hip joint; knee joint; muscle contraction; muscle resection; soft-tissue tumors; surgical treatment

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Removal of one or more muscles (myectomy) is often indicated in patients with an intra- or intermuscularly located malignant soft-tissue tumor. Even benign intramuscular tumors, such as extra-abdominal desmoid, lipoma, hemangioma, and myxoma, are often best treated by myectomy, growing as they do in an infiltrative manner. The hip and thigh, especially the latter, are common locations of both malignant and benign soft-tissue tumors. Concerning these anatomical sites information is lacking about the functional impairment that follows removal of a

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Table 1. Descriptive details of 46 patients in whom various hip and/or thigh muscles had been completely removed or completely denervated

IP = iliopsoas, TFL = tensor fasciae latae, R = rectus femoris, S = sartorius, I = iliacus, GMe = gluteus medius, GMi = gluteus minimus, Pi = piriformis, abGMa = abducting part of gluteus maximus, AL = adductor longus, AB = adductor brevis, St = semitendinosus, Pe = pectineus, AM = adductor magnus, GMa = whole gluteus maximus, VL = vastus lateralis, VI = vastus intermedius (part of VI = adjacent part), VM = vastus medialis (parts of VM = proximal parts), B = biceps femoris, Sm = semimembranosus.
Muscles within brackets do not contribute to the measured strength.
Impairment of function is given in demerit points (Table 2). 2–6 = slight, 7–14 = moderate and > 14 = considerable impairment of function; maximal score 39 before and 34 after the age of 60 years.

No.	Sex	Age at operation	Follow-up time (yrs)	Diagnosis	Loss of muscles(s)	Measured strength	Demerit points (DP)
1	F	52	6	Ganglion	IP	Hip flexion	2
2	M	70	2	Tuberculous granuloma	IP	Hip flexion	6
3	M	46	2.5	Malignant fibrous histiocytoma	TFL	Hip flexion* and abduction	10
4	M	61	4	Lipoma	TFL	Hip flexion and abduction**	8
5	M	48	13	Malignant fibrous histiocytoma	TFL+R+S	Hip flexion and abduction	7
6	M	26	7.5	Osteosarcoma	TFL+R+S+I+(GMe+GMi+Pi)	Hip flexion	9
					TFL+R+S+(I)+GMe+GMi+Pi	Hip abduction	
7	F	23	10	Desmoid	TFL+GMe+GMi+Pi+abGMa	Hip abduction	6
8	M	57	1	Myxofibrosarcoma	GMe+abGMa	Hip abduction**	4
9	M	51	0.5	Liposarcoma	GMe+abGMa	Hip abduction	6
10	F	41	7	Desmoid	AL	Hip adduction	0
11	M	71	4	Liposarcoma	AL+AB+St	Hip adduction	4
12	M	39	7	Desmoid	AL+AB+Pe	Hip adduction	0
13	M	58	1.5	Leiomyosarcoma	AL+AM+(VM)	Hip adduction*	11
14	F	54	1.5	Malignant mesenchycoma	AL+AB+AM	Hip adduction**	6
15	M	65	1.5	Liposarcoma	AL+AB+AM	Hip adduction	8
16	M	76	1	Malignant fibrous histiocytoma	AL+AB+AM	Hip adduction	9
17	M	27	2	Hemangioma	GMa	Hip extension	0
18	F	43	13	Fistulating pyogenous myositis	GMa	Hip extension	2
19	F	67	0.5	Malignant fibrous histiocytoma	GMa	Hip extension	2
20	M	10	1	Old muscle rupture	R	Hip flexion and knee extension	0
21	M	60	4	Benign fibrous tumoriform lesion	R	Hip flexion and knee extension	5
22	F	13	4	Hemangioma	VL	Knee extension	0

23	F	19	6	Hemangioma	VI	Knee extension	0
24	F	42	9	Synovial sarcoma	VM+(S)	Knee extension	4
25	M	64	11	Myxoma	VL+1/2VI	Knee extension	2
26	F	40	6	Myxofibrosarcoma	VL+1/2VI	Knee extension	9
27	M	44	3	Malignant fibrous histiocytoma	VM+1/2VI	Knee extension	2
28	F	50	4	Myositis ossificans	R+(VL)	Hip flexion	6
					R+VL	Knee,extension	
29	M	38	3.5	Lipoma	R+(VM)	Hip flexion	7
					R+VM	Knee extension	
30	M	35	0.5	Leiomyosarcoma	R+(VM)+S	Hip flexion	2
					R+VM+(S)	Knee extension	
31	F	53	1.5	Malignant fibrous histiocytoma	VM+VI	Knee extension	8
32	M	40	15	Hibernoma	R+(VL+VI)	Hip flexion	8
					R+VL+VI	Knee extension	
33	M	47	4	Fibrosarcoma	R+VM+VI	Knee extension	28
34	F	41	1	Fibrosarcoma	R+(VL+VI+1/3VM)	Hip flexion	14
					R+VL+VI+1/3VM	Knee extension	
35	M	41	17	Liposarcoma	R+VL+VI+1/2VM+(S)***	Knee extension	10
36	F	65	17	Malignant fibrous histiocytoma	R+VL+VI+1/2VM+(TFL+S)	Knee extension	11
37	F	72	2	Myxofibrosarcoma	St	Hip extension and knee flexion	0
38	F	21	3	Lipoma	St	Hip extension and knee flexion	0
39	F	49	11	Myositis	St	Hip extension and knee flexion	0
40	F	20	6	Lipoma	St	Hip extension and knee flexion	2
41	F	18	11	Hemangioma	B	Knee flexion	0
42	F	10	19	Hemangioma	B	Hip extension and knee flexion	0
43	F	27	2	Benign unclassified tumor	B	Hip extension and knee flexion	4
44	M	66	3	Liposarcoma	St+Sm+B	Hip extension and knee flexion	8
45	F	70	3	Malignant giant-cell tumor of soft tissue	St+Sm+B	Knee flexion	9
46	M	74	4	Fibrosarcoma	St+Sm+B+(AL+AB)+Am	Hip extension	15
					St+Sm+B+(AL+AB+Am)	Knee flexion	

* = Isokinetic strength not measured;
** = Isokinetic strength not measured at 180°/s;
*** = Tendon of the tensor fasciae latae (iliotibial band) transferred to the quadriceps tendon.

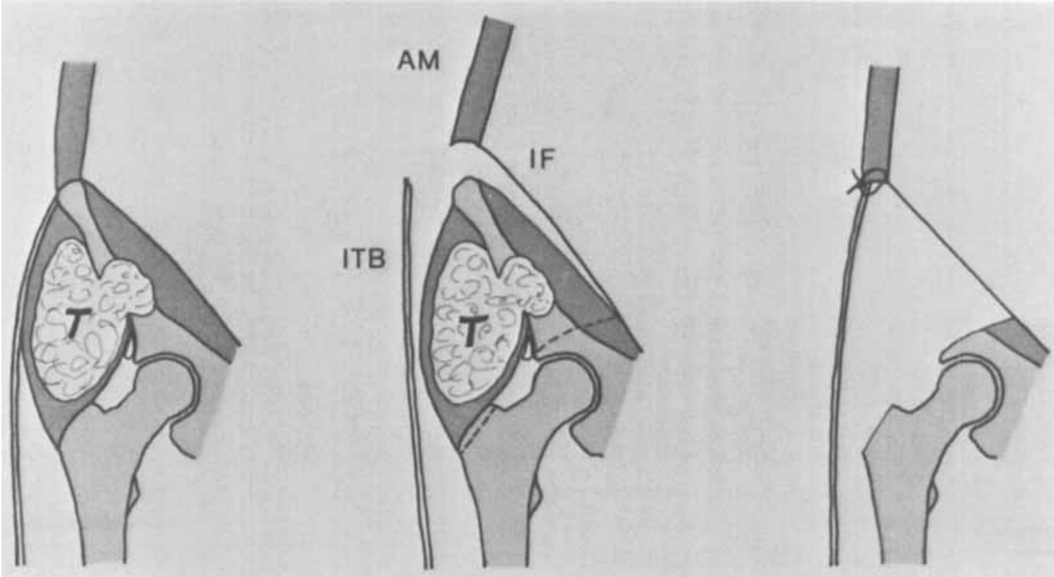

Figure 1. Case 6. Left. Osteosarcoma (T) arising from the iliac wing and protruding into the gluteus minimus and iliacus muscles. Middle. The iliotibial band (ITB) and the abdominal muscular wall (AM), the latter continuous with the iliac fascia (IF), have been released from the iliac crest. Interrupted lines indicate resection through the greater trochanter, the pelvic bone, and the iliacus muscle. Between the gluteus minimus and the resection line the tendon of the rectus femoris which was included in the specimen along with its origin, the anterior inferior iliac spine, can be seen. Right. After removal of the tumor specimen the iliotibial band has been attached to the abdominal muscular wall. The preserved iliac fascia prevents visceral herniation. The patient is free from evidence of disease more than 8 years after operation.

certain muscle or certain muscles. This investigation was undertaken with the aim of filling this gap in our knowledge, for the benefit of surgeons planning and performing such operations.

In the patients who participated in the investigation only well defined muscles or parts of muscles had been lost and this gave us an opportunity to study the importance of individual muscles for the strength generated around the hip and knee joints.

PATIENTS

Forty-six patients who had undergone excision or complete denervation of one or more hip and/or thigh muscles because of a soft-tissue tumor, or some other lesion, participated in this investigation. Sex, age at operation, follow-up time, diagnosis, and loss of muscle or muscles are given in Table 1.

One patient (No. 6) had as the only remaining abductor of the hip the abducting part of the gluteus maximus. Normally, this muscle exerts its abducting function via its insertion in the iliotibial band, whose proximal end is anchored to the iliac crest, and the posteriorly directed component of the muscle's abducting force is balanced by an anteriorly directed force generated by the tensor fasciae latae. In this patient the tensor fasciae latae had been included in the tumor specimen, along with the iliac wing and other muscles originating in this bone (Figure 1). The iliotibial band had thereafter been attached to the abdominal muscular wall, which had been released from the iliac crest.

In three patients (25, 26, 27) in whom either the vastus lateralis or vastus medialis had been removed, the adjacent half of the vastus intermedius had been included in the surgical specimen. In three patients (34, 35, 36) in whom the rectus femoris, vastus lateralis and vastus intermedius had been removed, the proximal third or half of the vastus medialis had been included in the specimen, whereas the distal two-thirds or half were preserved with intact innervation (branches of the saphenous nerve). In one of these patients (35), who had lost the proximal half of the vastus medialis, the tensor fasciae latae had been made an efficient extensor for the knee joint by transferring the distal part of the iliotibial band to the quadriceps tendon.

The follow-up time varied between 0.5 and 19 years (Table 1). No patient underwent planned physiotherapy after leaving the hospital. No patient had other disabilities that would influence the function of the lower limbs.

METHODS

Impairment of function was assessed with regard to: 1) unsteadiness, 2) limping, 3) walking support, 4) walking distance, 5) running, 6) walking up and down stairs, and 7) physical activity. The different factors were scored on a scale from 0 to maximum 8 demerit points (DP) (Table 2). Some factors that seemed to have less significance for elderly patients were scored lower over the age of 60 years. A score below 7 DP was regarded as slight, between 7 and 14 DP as moderate, and above 14 DP as considerable impairment of function. Change of occupation and occurrence of pain were also noted.

Clinical examination comprised the following measurements: the range of motion of the knee and hip joints, the thigh circumference 20 cm above the medial joint space of the knee, the highest step the patient could mount and descend with the operated leg first and last, respectively, and the ability to rise from squatting. In patients who had lost quadriceps muscles, the movement of the patella during flexion and extension was examined by inspection and palpation. In patients who had lost one or more hip abductors, the result of Trendelenburg's test was classified as no, slight, or pronounced pelvic tilt.

Muscle strength generated around the hip and knee joints was measured isometrically and isokinetically using a Cybex II dynamometer (Lumex, New York). Table 1 gives the measured strength (flexion, abduction, adduction, and extension in the hip joint; extension and flexion in the knee joint) for each of the 46 patients. The strength was measured in the movements of the hip and knee joints in which the extirpated muscle or muscles have an important function (Lang & Wachsmuth 1972). The strength of the different movements in the hip joint was recorded in the supine

Table 2. Demerit point (DP) system for evaluation of impairment of function

			Under 60 years	Over 60 years
1. *Unsteadiness*	none		0	0
	periodically		2	2
	regularly on exertion		4	4
	regularly at normal activity		6	6
2. *Limping*	none		0	0
	following exertion		2	2
	always		4	4
3. *Walking support*	none		0	0
	cane outdoors		4	4
	cane always		6	6
	crutches		8	8
4. *Walking distance*	not impaired		0	0
	under 5 km		4	2
	under 1 km		6	4
5. *Running*	normal		0	0
	slightly impaired		2	0
	much impaired		4	2
	cannot run		6	3
6. *Walking up and down stairs*	normal		0	0
	slowly, alternating steps		2	2
	healthy leg first and last, respectively		4	4
7. *Physical activity*	mainly sedentary	0		
activity	walking	2		
(DP = the difference	long distance walking	3	0–5	0–5
between pre- and	regular exercise	4		
postoperative scores)	competitive sports	5		
		Maximum score	39	34

Table 3. Mean ($\bar{X}$) and standard deviation (d) for the knee extension strength recordings on the non-operated side. Torque is given in Nm

		Men $n = 9$ Mean age 47 years X̄	 d	Women $n = 8$ Mean age 49 years X̄	 d
Isometric strength	30°	86.4	32.1	75.9	31.2
	60°	162.9	59.4	134.7	46.3
	90°	201.1	103.3	128.8	45.5
Isokinetic strength	30°/s	183.8	93.2	126.6	39.1
	90°/s	155.2	67.2	95.6	31.8
	180°/s	106.1	40.3	66.8	24.6

position and the dynamometer was placed in a manner described elsewhere (Markhede & Grimby 1980). The strength of knee extension and flexion was recorded in the seated position with the trunk and the opposite thigh firmly fixed with straps; when knee flexion strength was recorded a strap was also applied over the relevant thigh. The seated position was chosen because it is most commonly used in measurements of knee extension strength and the knee flexion strength is then greater than in the prone position (Williams & Stutzman 1959). The rotation center of the dynamometer was placed level with the estimated axis of the knee joint. The generated torque was registered on an x-y-writer (Omnigraphic Huston Instruments).

Flexion and extension torques in the hip and knee joints were measured isometrically at 30, 60, and 90° of flexion (straight = 0°) and isokinetically at three different angular velocities (30°/s, 90°/s, 180°/s)*. Abduction and adduction torques in the hip joint were measured isometrically at 0 and 30° of abduction and isokinetically at the same velocities as above. The adduction torque was, in addition, measured isometrically at 15° of abduction. The best of three maximal performances in each position and each speed was used. Between the recordings the patients were allowed to rest for 2 minutes.

At the isokinetic recordings the "peak torque" and its position in the range of motion were registered. The range of motion was approximately 100°. The isokinetic torque at 30 and 60° of knee flexion was recorded to enable comparison to be made with the isometric torque at the same angles of flexion. The strength on the operated side was calculated in relation to that on the non-operated side. Systematic errors were avoided by alternating the "starting" side. Table 3 gives the mean values of knee extension strength on the reference side. Student's *t*-test for small samples was used and $P < 0.05$ was considered significant.

*180°/s = πr/s

RESULTS

Impairment of function (Table 1)

Eleven patients had *no* impairment of function (0 DP). All except one had lost only one muscle (adductor longus, gluteus maximus, rectus femoris, vastus lateralis, vastus intermedius, semitendinosus, or biceps femoris); the exceptional patient (12) had lost the adductor longus, adductor brevis and pectineus. Seventeen patients had a *slight* impairment of function (2–6 DP). Seven of them had lost one, 4 one and a half, 2 two, 4 three, and 1 four and a half muscles. Of those who had lost three muscles, one (14) had lost all the prime adductors (longus, brevis and magnus). In the patient (7) who had lost four and a half muscles, only the rectus femoris and sartorius remained as hip abductors (Figure 2).

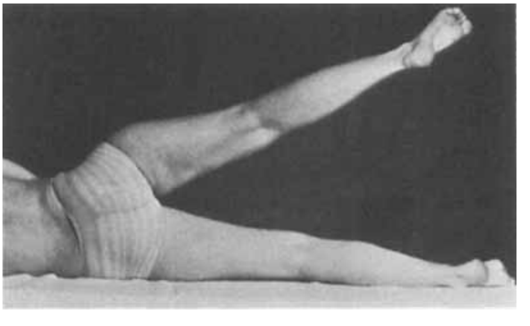

Figure 2. Case 7. At operation the patient lost all abductors of the hip joint except the rectus femoris and sartorius. From Stener (1978). Courtesy of the editor of International Orthopaedics.

Sixteen patients had a *moderate* impairment of function (7–14 DP). All except five (3, 4, 26, 29, 31) had lost at least three muscles. In one patient (6) who had lost seven muscles the only remaining hip abductor was the abducting part of the gluteus maximus (Figure 1). Only two patients had *considerable* impairment of function. One of them (33) had lost three muscles and the other (46) six (all hamstrings and all prime adductors).

Extirpation of less than three quadriceps muscles resulted in from 0 to 9 demerit points, extirpation of three or more in from 8 to 28 demerit points. Extirpation of the rectus femoris, which is both an extensor of the knee and a flexor of the hip, did not seem to reduce the function more than extirpation of other parts of the quadriceps.

A common symptom was unsteadiness, which 25 patients experienced to some degree. Of the 21 patients who did not experience unsteadiness, 13 had lost only one muscle, but one (7) had lost as many as four and a half muscles (all hip abductors except the rectus femoris and sartorius). All seven patients who had lost one or more hip abductors limped, as did eight other patients; six of them had lost at least three muscles (hip adductors, quadriceps muscles, or hamstrings). The patient (6) whose only remaining hip abductor was the abducting part of the gluteus maximus (Figure 1) had a less pronounced Trendelenburg limp while running than while walking. (In his spare time he worked as a coach for a soccer team.) Two patients (33, 36) used a cane outdoors; one of them (33) had a walking distance below 1 km. Thirty-one patients had some degree of impaired running ability. Of the 15 patients who could run unhindered, all but one (12) had lost only one muscle. Six patients could not run at all; they had lost three to six muscles. All but two patients (26, 33) could walk unhindered up and down stairs. Physical activity was unchanged in 33 patients and reduced only one step in 10. The three patients (13, 35, 45) who had a more significant reduction (two steps) of physical activities had lost at least three muscles. Only one patient (33) had changed occupation (50 per cent disability pension). No patient had pain.

Clinical examination

Four patients (2, 3, 13, 19) had restricted hip motion (10–20°). All patients could actively extend the knee fully; that is, they could achieve the screw-home effect. Eight patients (13, 26, 30, 31, 33, 34, 45, 46) had restricted knee flexion; the limitation did not exceed 30° compared with the non-operated side, however, and no patient had noticed it.

No patient had any symptoms from their femoropatellar joint and no abnormal movement of the patella during extension and flexion of the knee could be observed. All patients but two (26, 36) could mount and descend a step of at least 30 cm height with the operated leg first and last, respectively. All patients but three (13, 26, 33) could rise from squatting.

When tested for the Trendelenburg sign, five patients showed a slight and two a pronounced pelvic tilt. A slight tilt was seen in two patients (3, 4) who had lost the tensor fasciae latae alone, in one (5) who had also lost the rectus femoris and sartorius, and in two (8, 9) who had lost the gluteus medius and the abducting part of the gluteus maximus. A pronounced tilt was seen in the patient (6) whose only remaining abductor was the abducting part of the gluteus maximus and in the patient (7) whose only remaining abductors were the rectus femoris and sartorius.

One patient had slight edema in the thigh and one a moderate edema in the leg and thigh.

Measurements of hip flexion strength (Figure 3)

When the iliopsoas had been lost (1, 2), the isometric strength reduction became more pronounced the more the hip was flexed (Figure 3 top left). The isokinetic strength reduction also became more pronounced with increasing hip flexion: the peak torque was located around 30° of flexion; this torque varied in the two patients and at the three different angular velocities between 50 and 79 per cent (Figure 3 top right).

When only the tensor fasciae latae had been lost (3, 4), the least strength reduction was observed at 90° of hip flexion, whereas additional removal of the rectus femoris and sartorius (5) and of these muscles and the iliacus (6) resulted

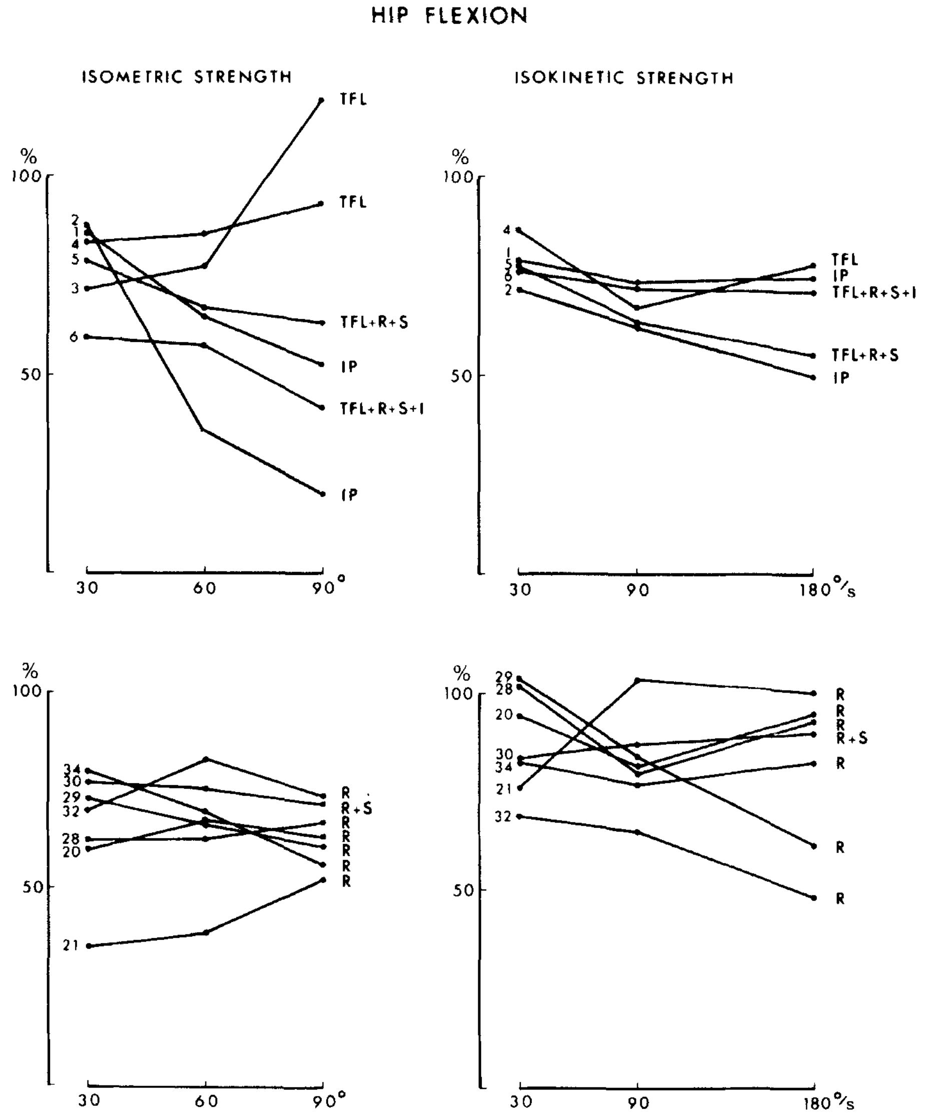

Figure 3. Hip flexion strength in relation to the non-operated side (per cent) in 13 patients who had lost various hip flexors (for patient numbers and abbreviations see Table 1). Isometric strength tested in different angular positions and isokinetic strength (peak torque) at different angular velocities.

in the greatest strength reduction at 90° (Figure 3 top left). The patient who had lost four hip flexors (6) demonstrated less reduction of hip flexion strength isokinetically than isometrically.

In six patients (20, 21, 28, 29, 32, 34) who had lost the rectus femoris alone as a hip flexor and in one (30) who had also lost the sartorius (Figure 3 bottom), the hip flexion strength was measured. In the six patients who had lost the rectus femoris alone, the mean isometric strength was 63 per cent and the mean isokinetic strength 83 per cent. The peak on the average isokinetic torque curve was shifted somewhat (10°) towards a more extended position of the hip on the operated side compared with the non-operated side.

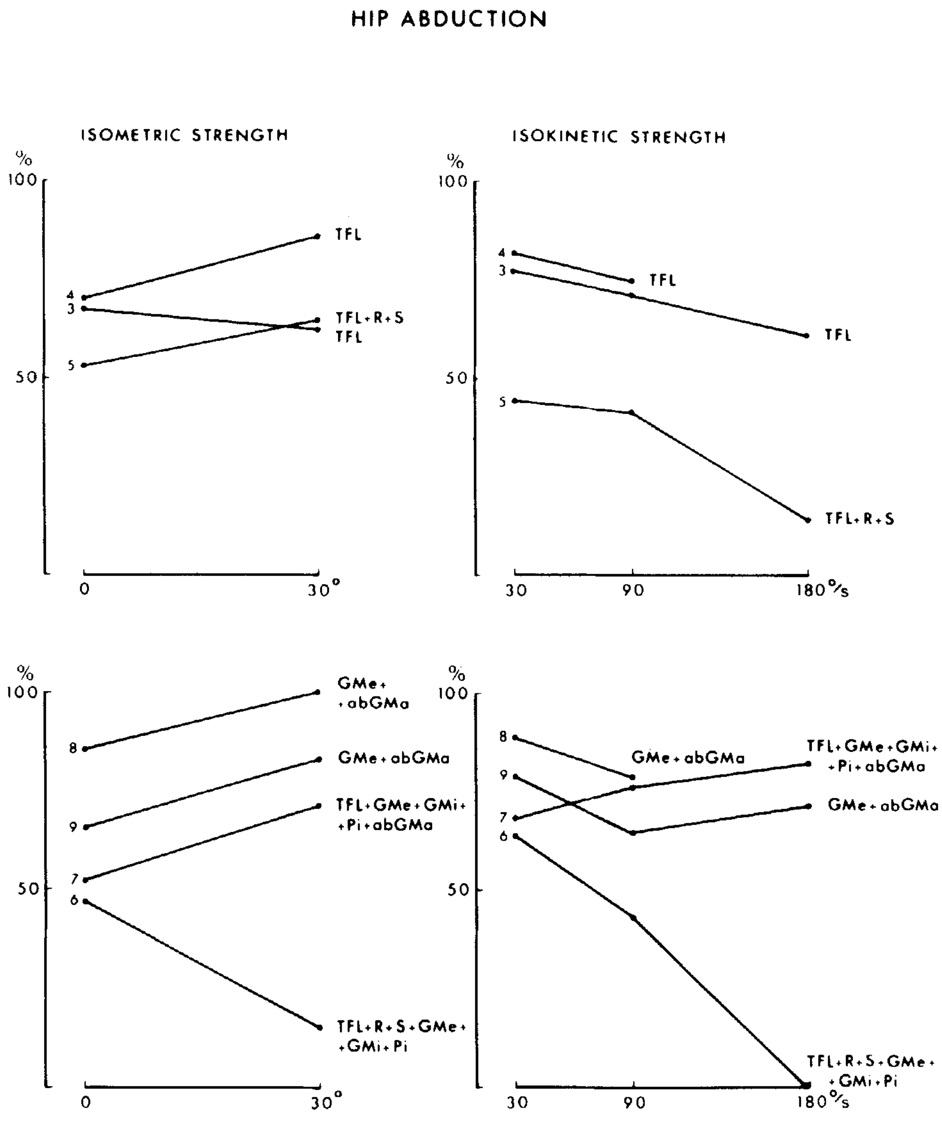

Figure 4. Hip abduction strength in relation to the non-operated side (per cent) in 7 patients who had lost various hip abductors (for patient numbers and abbreviations see Table 1). Isometric strength tested in different angular positions and isokinetic strength (peak torque) at different angular velocities.

Measurements of hip abduction strength (Figure 4)

When only the tensor fasciae latae had been removed (3, 4), the isometric abduction strength was 62–86 per cent (Figure 4 top left) and the isokinetic strength 61–82 per cent (Figure 4 top right). Additional removal of the rectus femoris and sartorius (5) resulted in further reduction of the abduction strength, especially of the isokinetic strength at the highest angular velocity (Figure 4 top right).

Hip abduction strength was measured in two patients (8, 9) who had lost the gluteus medius and the abducting part of the gluteus maximus, in one (7) who had lost all abductors except the rectus femoris and sartorius, and in one (6) who had as the only remaining abductor the abducting part of the gluteus maximus which exerted its function via the iliotibial band whose proximal end, after resection of the iliac wing, had been attached to the abdominal muscular wall (Figure 1). The results are graphically presented in Figure 4 (bottom). In the patient (7) whose only remaining abductors were the rectus femoris and sartorius, the isometric strength was 52 per cent in the neutral position and 71 per cent when the hip was abducted 30°; the isokinetic abduction strength was, at higher angular velocities, even less reduced. The isometric abduction strength at 30° of abduction exceeded that in the neutral position even in the two patients (8, 9) who had lost the gluteus medius and the abducting part of the gluteus maximus. In the patient whose only remaining abductor was the abducting part of the gluteus maximus (6), the isometric strength was 47 per cent in the neutral position, but he could not maintain this strength when the hip was abducted 30°. Isokinetically, he had good abduction strength at low angular velocity but none at high angular velocity (Figure 4 bottom right).

Measurements of hip adduction strength (Figure 5)

The loss of the adductor longus alone (10) did not cause any reduction of the isometric or isokinetic adduction strength. When also the adductor brevis and semitendinosus (11), or the adductor brevis and pectineus (12), or the adductor magnus (13) had been removed, the isometric strength was 55–84 per cent, and when the adductor longus, brevis and magnus had been removed (14, 15, 16), it was 20–36 per cent.

With all these three adductors removed the isokinetic strength exceeded the isometric strength at the angular velocity of 30°/s.

Measurements of hip extension strength (Figure 6)

In three patients (17, 18, 19) who had lost the whole gluteus maximus, the mean isometric hip extension strength was 94 per cent and the mean isokinetic strength 81 per cent.

In four patients (37, 38, 39, 40) who had lost

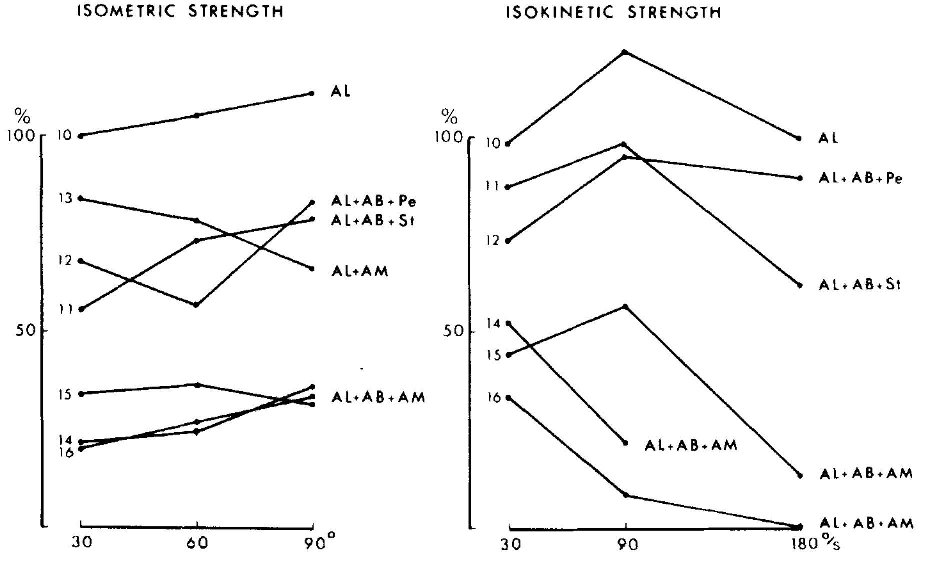

Figure 5. Hip adduction strength in relation to the non-operated side (per cent) in 7 patients who had lost various hip adductors (for patient numbers and abbreviations see Table 1). Isometric strength tested in different angular positions and isokinetic strength (peak torque) at different angular velocities.

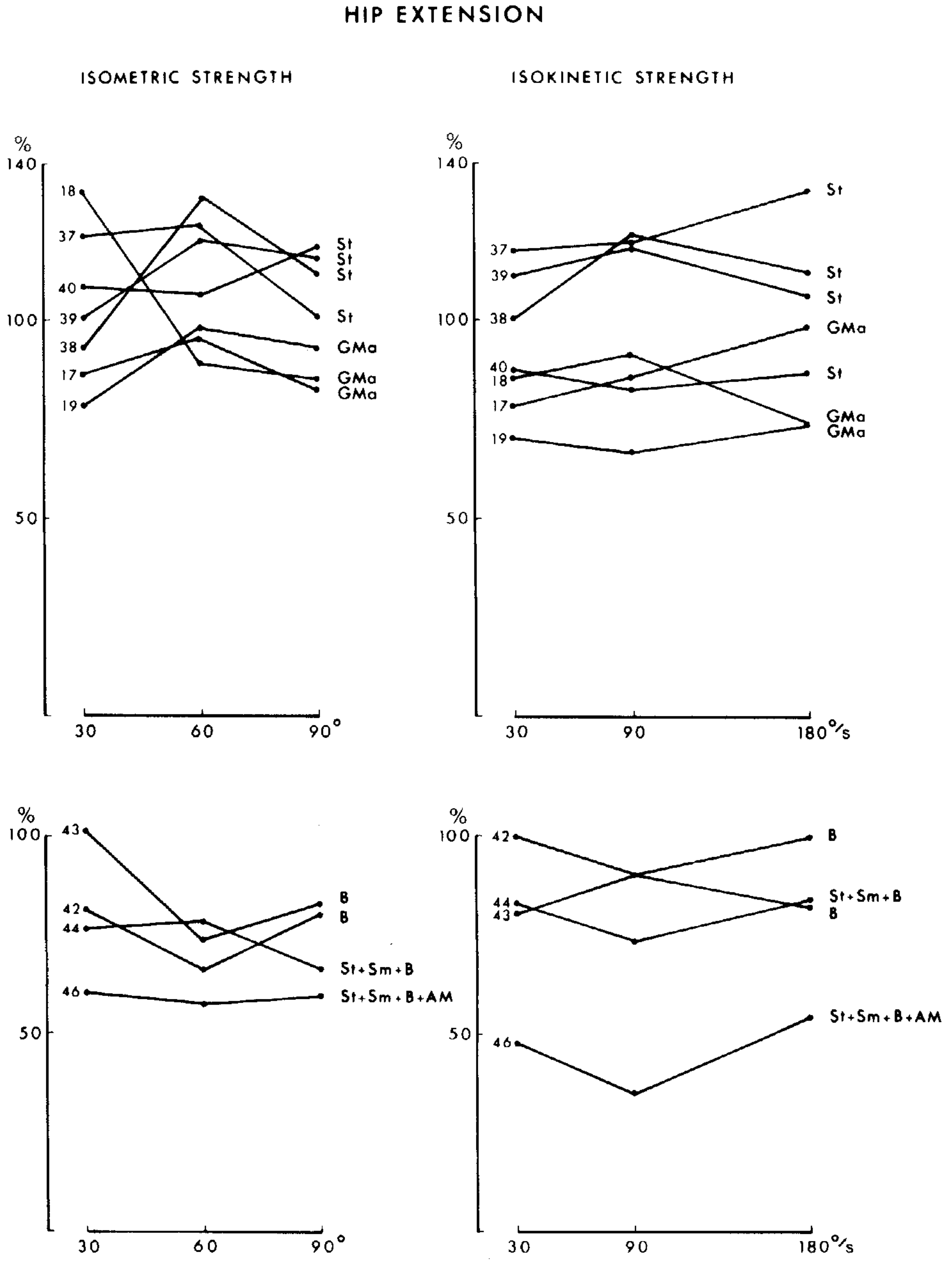

Figure 6. Hip extension strength in relation to the non-operated side (per cent) in 11 patients who had lost various hip extensors (for patient numbers and abbreviations see Table 1). Isometric strength tested in different angular positions and isokinetic strength (peak torque) at different angular velocities.

the semitendinosus, there was no strength reduction. In two patients (42, 43) who had lost the biceps femoris, the mean isometric strength was 81 per cent and the mean isokinetic strength 91 per cent. In one patient (44) who had lost all the hamstring muscles, the mean isometric strength was 74 per cent and the mean isokinetic strength 80 per cent, and in one (46) who had also lost the three prime adductors (longus, brevis, magnus), the mean isometric strength was 59 per cent and the mean isokinetic strength 46 per cent (the adductor magnus is an extensor for the hip when the joint is flexed as in the present strength measurements).

Measurements of knee extension strength (Figures 7 and 8)

The isometric knee extension strength in 17 patients (Nos. 20–36 in Table 1) who had lost one, one and a half, two, three, or more than three quadriceps muscles is illustrated in Figure 7. Calculation of the mean extension strength for each of the five groups of patients (three different angles of knee flexion in each patient) gave the following results: 78 per cent when only one muscle had been removed (Figure 7 top left), 69 per cent when in addition to the vastus medialis or lateralis the adjacent half of the vastus intermedius had been removed (Figure 7 top right), 67 per cent when two muscles had been removed (Figure 7 middle left), 45 per cent when three muscles had been removed (Figure 7 middle right) and 24 per cent when more than three muscles had been removed without any compensatory muscle transference (Figure 7 bottom). In the patient (35) in whom the tendon of the tensor fasciae latae had been transferred to the quadriceps tendon, the mean extension strength was 44 per cent. Removal of the rectus femoris alone (20, 21) resulted in a mean strength reduction of barely 10 per cent, and the combined removal of this muscle and the vastus medialis or lateralis (28, 29, 30) resulted in a mean strength reduction of 22 per cent.

The reduction of the isometric knee extension strength was greater in the more flexed positions of the joint. Thus, the mean (n = 17) extension strength was 68 ± 28, 64 ± 26, and 54 ± 25 per cent at 30, 60, and 90° of flexion, respectively. Consequently, the strength reduction tended to be greatest in that part of the range of motion where the torque is normally greatest. The difference between the extreme positions (30 and 90°) was significant (paired t-test).

The isokinetic knee extension strength in the 17 patients is illustrated in Figure 8 (peak torque for three different angular velocities). In the group of patients who had lost only one muscle, the mean isokinetic strength was almost the same as the mean isometric strength, whereas it was less than this in the other groups. The mean strength was 79, 56, 53, 22, and 14 per cent, respectively, in the five groups. In the patient (35) whose loss of more than three muscles had been compensated for to some extent by transfer of the tensor fasciae latae, the mean extension strength was 35 per cent. In the whole group of 17 patients there was no obvious difference in isokinetic knee extension strength (peak torque) at different angular velocities.

The configuration of the torque curve differed from that of the non-operated side. When the strength fell below 40 Nm the curve became low and elongated and without a clearly defined peak (four patients). In the 13 patients who had a clearly defined peak, it shifted significantly towards a more extended position of the knee (average 9.0°) at the angular velocity of 30°/s; at 90°/s the peak shifted in the same direction (average 3.4°), but this shift was not significant.

The reduction of isokinetic strength was greatest at 70–80° of the knee flexion and decreased when the knee was more extended or more flexed. This is illustrated in Figure 9 at the angular velocity of 30°/s, and the same tendency was found at 90°/s. The calculation becomes uncertain when the angle of knee flexion is below 30° and when the angular velocity is 180°/s because the numerical values are low and the variation becomes greater.

Correlations regarding loss of quadriceps muscles

The correlation between the isometric and isokinetic strength reduction at 60° of knee flexion was strongest at the angular velocity of 30°/s (r = 0.95) and somewhat weaker at higher velocities (r = 0.85 and 0.87 at 90°/s and 180°/s, respectively). The isokinetic strength reduction was usually greater than the isometric strength reduction. The difference was statistically significant (paired t-test) and increased as the angular velocity increased. The mean difference was 9.4,

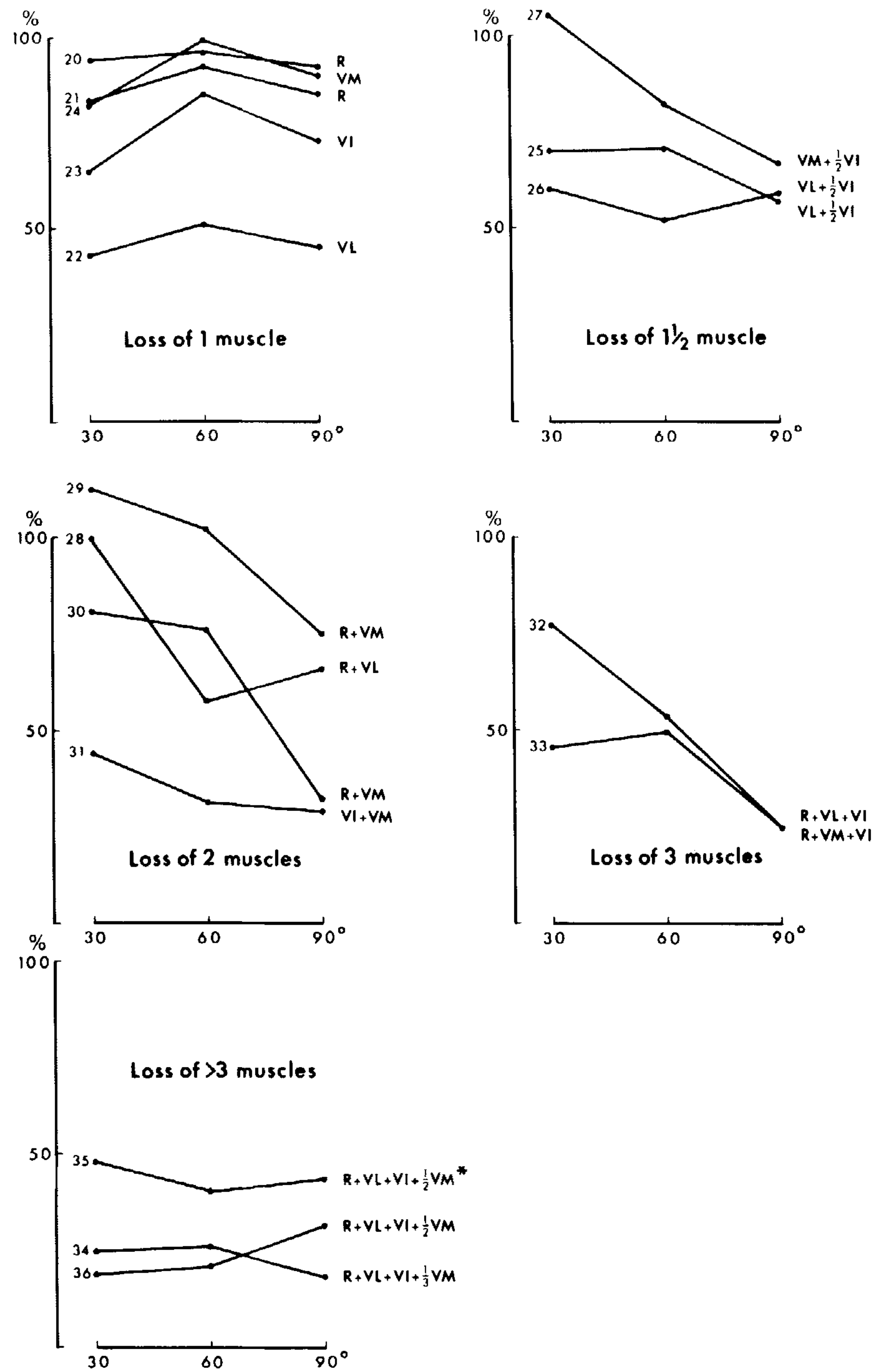

Figure 7. Isometric knee extension strength in relation to the non-operated side (per cent) at three different angles of knee flexion in 17 patients who had lost various knee extensors (for patient numbers and abbreviations see Table 1). Asterisk denotes patient in whom the tendon of the tensor fasciae latae (the iliotibial band) had been transferred to the quadriceps tendon.

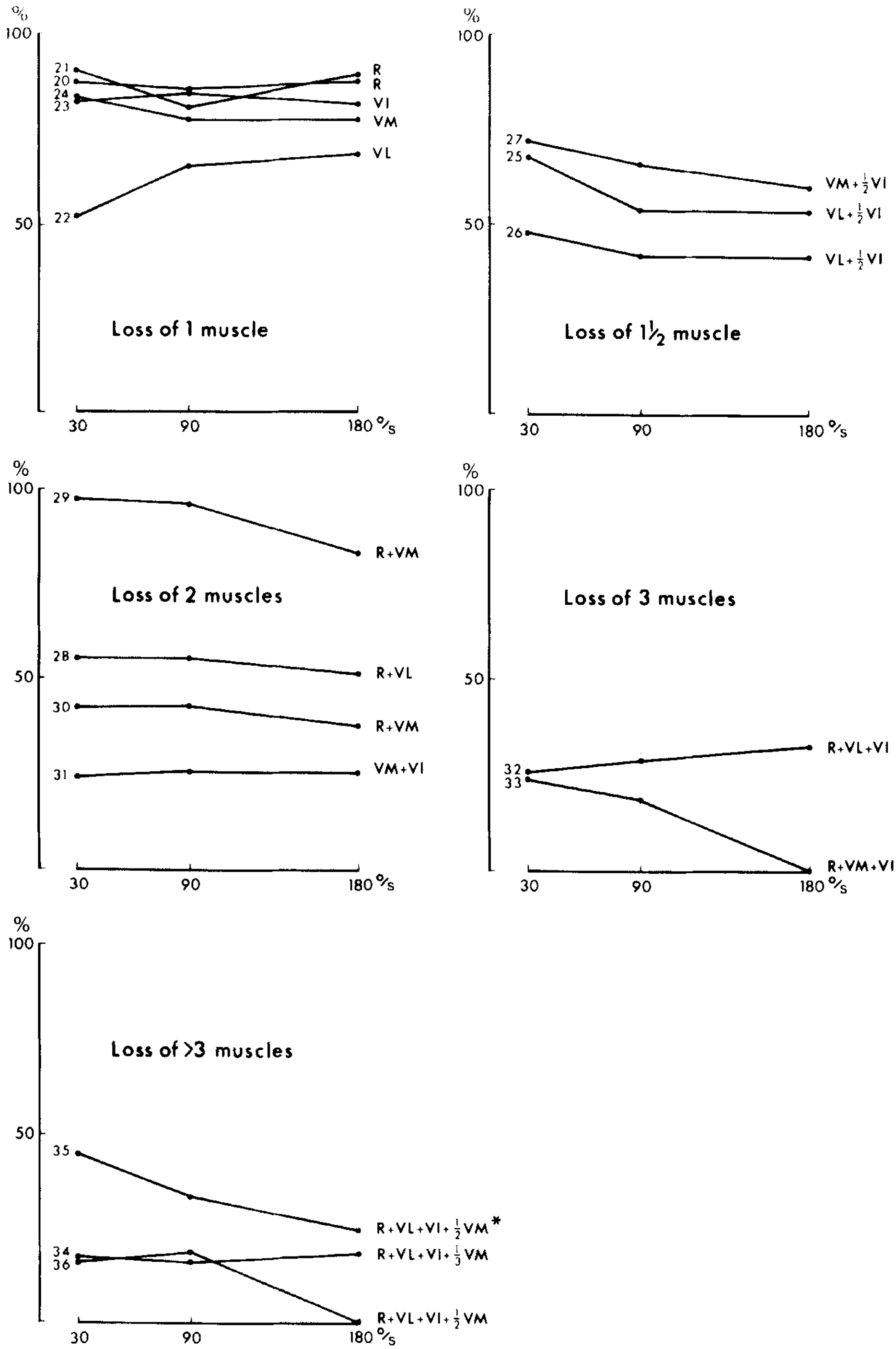

Figure 8. Isokinetic knee extension strength (peak torque) in relation to the non-operated side (per cent) at three different angular velocities in 17 patients who had lost various knee extensors (for patient numbers and abbreviations see Table 1). Asterisk denotes patient in whom the tendon of the tensor fasciae latae (the iliotibial band) had been transferred to the quadriceps tendon.

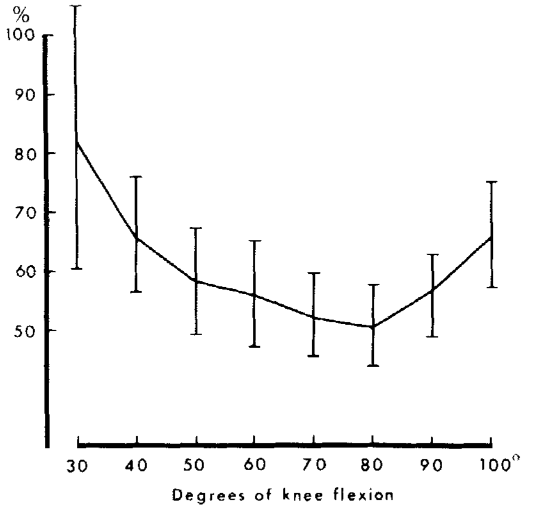

Figure 9. The mean reduction (± SEM) of isokinetic strength (30°/s) in different angular positions of the knee during extension (n = 17).

11.4 and 14.8 per cent at angular velocities of 30, 90 and 180°/s, respectively.

There was a progressive impairment of function (measured in demerit points) with decreasing knee extension strength. The impairment of function was most strongly correlated with the isokinetic peak torque reduction at the angular velocity of 180°/s (r = 0.75). The correlation was weaker between the isometric strength reduction (mean of recordings in three angular positions) and the impairment of function (r = 0.56). Figure 10 illustrates the correlation between the impairment of function and the mean strength reduction of all six recordings (three angular positions and three angular velocities) (r = 0.63). If the loss of strength did not exceed 50 per cent the impairment of function was usually slight (< 7 DP), whereas a strength reduction exceeding 50 per cent caused moderate or considerable impairment of function (> 7 DP).

There was no correlation between the reduction of hip flexion strength caused by the loss of the rectus femoris and impairment of function (measured in DP). Nor was there any correlation between the strength reduction in knee extension and that in hip flexion; in other words a progressive decrease of the knee extension strength did not cause a progressive decrease in hip flexion strength.

The reduction of the circumference of the thigh correlated well with the reduction of the knee extension strength (r = 0.80; isometrically 0.73, isokinetically 0.83) (Figure 11).

Measurements of knee flexion strength (Figure 12)

The knee flexion strength in 10 patients (Nos. 37–46 in Table 1) who had lost one or all hamstring muscles is illustrated in Figure 12. In four patients who had lost the semitendinosus (Figure 12 top), the mean isometric strength was 76 per cent and the mean isokinetic strength 94 per cent. At 30° of knee flexion the mean isometric strength reduction was barely 10 per cent whereas it was 40 per cent at 90° of flexion.

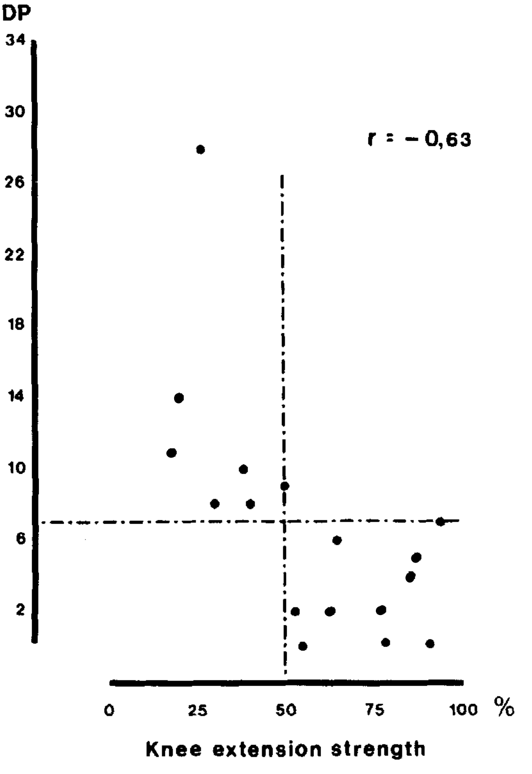

Figure 10. Correlation between the mean isometric and isokinetic knee extension strength in relation to the non-operated side (per cent) and the impairment of function expressed in demerit points (DP) (n = 17).

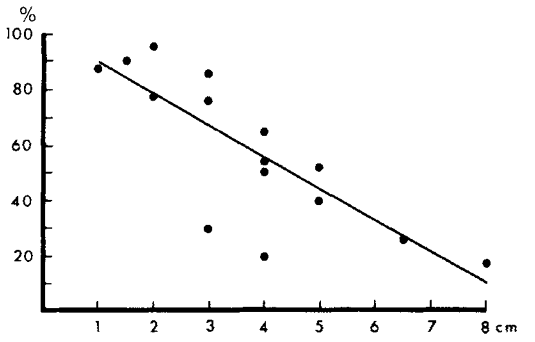

Figure 11. Correlation (r = 0.80) between the knee extension strength and the reduction of thigh circumference (n = 15; 2 patients with edema excluded).

In three patients who had lost the biceps femoris (Figure 12 bottom), the mean isometric strength was 72 per cent and the mean isokinetic strength 82 per cent, and in three patients who had lost all three hamstrings (Figure 12 bottom), the mean isometric strength was 33 per cent and the mean isokinetic strength 37 per cent.

In the whole hamstring group (10 patients), the isometric strength at 30° tended to be less than the isokinetic strength at 30°. The difference was not significant but increased as the angular velocity increased (2.8, 3.2 and 7.3 per cent at 30, 90 and 180°/s, respectively).

Correlations regarding loss of hamstring muscles

There was a good correlation between the reduction of hip extension strength caused by the loss of hamstring muscles and the reduction of knee flexion strength (r = 0.79).

The reduction of the circumference of the thigh correlated well with the reduction of the knee flexion strength (r = 0.78).

DISCUSSION

Several previous investigations into the contribution of different muscles to the torque generated around the hip and knee joints have been published (Fick 1911, Inman 1947, Pohtilla 1969, Waters et al. 1974). These investigations, however, are based on experimental and theoretical calculations and are of little help for prediction of the reduction of strength after muscular resections. Compensatory mechanisms like hypertrophy of the remaining muscles may cause the preserved strength to deviate from the calculated value. Studies similar to ours have not previously been reported.

Methods. The strength on the operated side was calculated in relation to that on the non-operated side (percentage). The experimental error (measured by the test-retest procedure) of the methods employed for measuring the strength in the hip joint varies between 4 and 10.5 per cent (Markhede & Grimby 1980), and the absolute values on the non-operated side did not differ significantly from those of a reference group studied by Markhede & Grimby (1980). When the knee extension strength on the non-operated side in our series was compared with reference values obtained previously with the same equipment and testing position as those we used (Aniansson et al. 1978, Krotkiewski et al. 1979, Larsson et al. 1979), no systematic difference was found. Even in normal subjects there are differences in strength between symmetrical muscle groups and the difference has to exceed 15–20 per cent to be considered pathologic (Heeböll-Nielsen 1964, Damholt & Termansen 1978).

Impairment of function. No patient complained spontaneously of impaired function; they apparently compensated well for their disabilities. Common to almost all patients who experienced any kind of disability, regardless of the function of the lost muscle or muscles, was a feeling of unsteadiness and/or reduced running ability. In patients who had lost important hip abductors, limping was a constant sign, which makes the rating for this group somewhat high (4–10 DP) although their other disabilities were slight.

In the quadriceps group, the reduction of the isokinetic knee extension strength (peak torque) at the angular velocity of 180°/s correlated best with the impairment of function. The determination coefficient (r^2) was 0.56, which means that 56 per cent of the disabilities could be explained by the strength reduction. Other factors that may

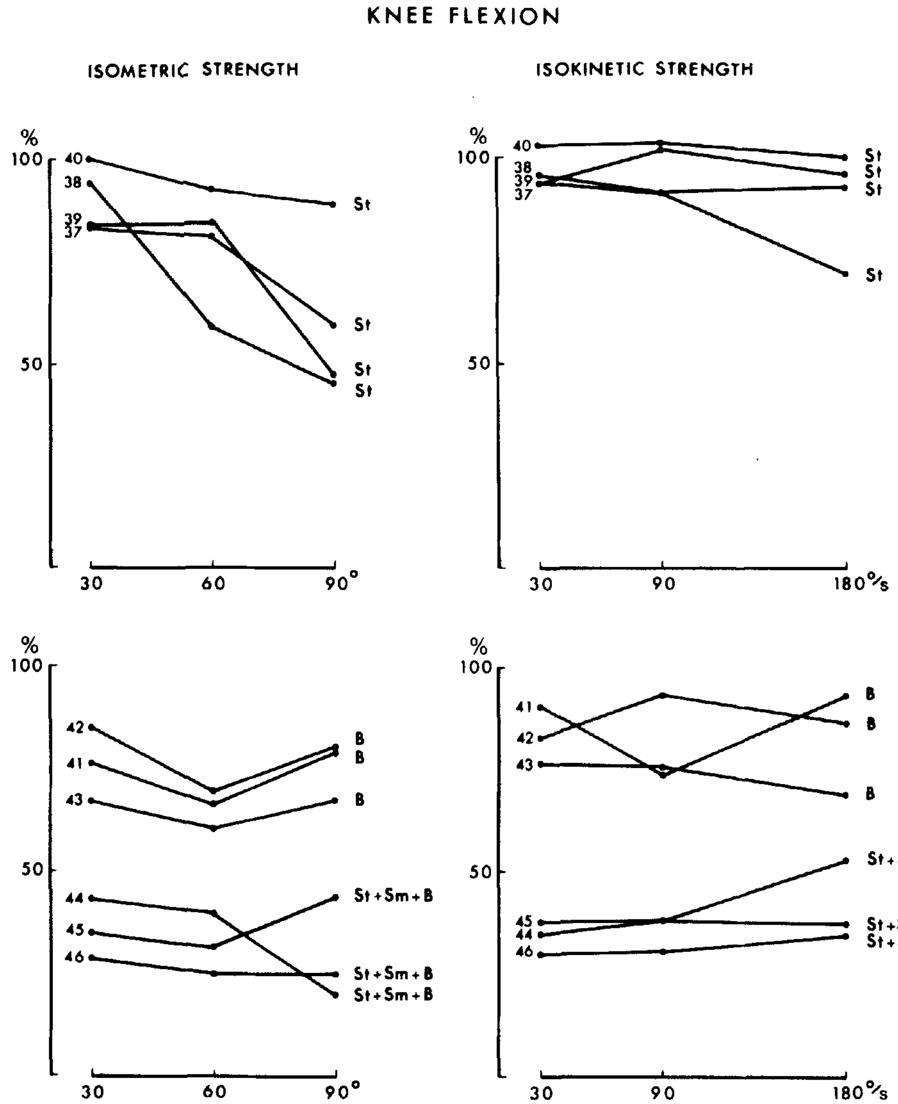

Figure 12. Knee flexion strength in relation to the non-operated side (per cent) in 10 patients who had lost various knee flexors (for patient numbers and abbreviations see Table 1). Isometric strength tested in different angular positions and isokinetic strength (peak torque) at different angular velocities.

influence the degree of impairment of function are the age of the patient and the follow-up time. Reduction of the knee extension strength by less than about 50 per cent caused as a rule only slight impairment of function (< 7 DP). This corresponded to loss of one, one and a half, or two quadriceps muscles. The reduction of the hip flexion strength when the rectus femoris had been included in the resection did not seem to cause increased disability.

Strength reduction and disability correlated in the hamstring group also. The function was not impaired or only slightly impaired when only the semitendinosus or biceps femoris had been removed whereas it was moderately impaired (7–14 DP) when all the hamstrings had been removed. The only considerably disabled patient in this group had in addition undergone removal of the three prime hip adductors, and he was 78 years old.

Clinical findings. The tensor fasciae latae and the gluteus maximus both act as abductors of the hip joint via their insertion in the iliotibial band. The former muscle seems to be more important than the latter for preventing pelvic tilt. All five patients who had lost the tensor fasciae latae, even those two who had lost this muscle alone, showed a positive Trendelenburg sign, whereas this sign was negative in all three patients who had lost the gluteus maximus alone. A positive Trendelenburg sign was seen, however, in the two patients who had lost the gluteus medius in addition to the abducting part of the gluteus maximus.

Subluxation of the patella was not seen in any patient in whom the vastus medialis had been removed, despite the fact that the distal oblique part of this muscle is considered to be of special importance for patellar alignment (Lieb & Perry 1968).

The reduction of the circumference of the thigh correlated well with the reduction of the knee extension strength after removal of quadriceps muscles (r = 0.80) and with the reduction of the knee flexion strength after removal of hamstring muscles (r = 0.78). Damholt & Zdravkovic (1972) and Zdravkovic & Damholt (1978) found this correlation very small (r = 0.27 and 0.39, respectively) after femoral fractures. One possible explanation is that the reduction of the circumference in our series corresponds to an actual reduction of the muscle mass whereas after a fracture some muscle tissue has been replaced by other tissue (connective tissue, callus, fat).

Hip flexion strength. According to Fick (1911), the iliopsoas is responsible for 22 per cent of the hip flexion strength. In our two patients who had lost the iliopsoas alone, the reduction of the isometric flexion strength was somewhat less than this figure when the hip was flexed 30° but greatly exceeded it when the hip was flexed 90° (Figure 3 top left). It seems that the iliopsoas becomes more important as a hip flexor with increasing flexion of the joint. The explanation is probably that the lever of the iliopsoas increases so much as the hip flexes that this more than compensates for the progressive shortening of the muscle. Our findings agree with those of Flint (1965) and LaBan et al. (1965), who found little electromyographic activity in the iliopsoas during the first 30–45° of hip flexion. In contrast to the iliopsoas, the tensor fasciae latae appeared to be of little importance as a hip flexor when the joint was flexed 90° (Figure 3 top left).

According to Fick (1911), the rectus femoris is responsible for 37 per cent of the hip flexion strength. In our six patients who had lost this muscle alone as a hip flexor, the mean reduction of the hip flexion strength agreed perfectly well with this value isometrically (37 per cent), but was considerably less isokinetically (17 per cent). The reduction of the isometric hip flexion strength after removal of the rectus femoris was about the same at different pelvo-femoral angles, which may be due to the fact that the lever for this muscle remains more or less unchanged during the movement. Another reason may be that shortening of the muscle was counteracted by the knee being progressively flexed along with increasing flexion of the hip.

Hip abduction strength. In the neutral position of the joint the isometric hip abduction strength was reduced by less than 50 per cent in all patients but one in whom this strength was measured, and the exceptional patient had not lost more than 53 per cent although he had only the abducting part of the gluteus maximus left as an abductor. The good abduction strength in these patients might possibly be the result of a compensatory hypertrophy of remaining abductor muscle or muscles. In an attempt to assess this possibility, our values were compared with those of Fick (1911) (Table 4). When the tensor fasciae latae had been removed alone (3, 4), or along with the rectus femoris and sartorius (5), the measured strength corresponded to the calculated value, even several years after the operation. Perhaps the muscular loss in these three patients had not been important enough to induce a compensatory hypertrophy. However, in the other four patients (6, 7, 8, 9) in whom abduction strength was measured, a compensatory hypertrophy of re-

Table 4. Comparison between calculated and measured hip abduction strength (per cent) in 7 patients who had lost various hip abductors (for abbreviations see Table 1)

No.	Loss of muscle(s) tested	Calculated strength (%) for abduction from 0°–50°	Measured isometric abduction strength (%) 0°	30°	Measured isokinetic abduction strength (%) 30°/s	90°/s	180°/s	Follow-up time (yrs)
3	TFL	83	67	62	77	71	61	2.5
4	TFL	83	70	86	82	75	–	4
5	TFL+R+S	60	53	64	44	41	14	13
6	TFL+R+S+GMe+GMi+Pi	19	47	15	63	43	0	7.5
7	TFL+GMe+GMi+Pi+abGMa	23	52	71	67	75	82	10
8	GMe+abGMa	57	85	100	89	77	–	1
9	GMe+abGMa	57	65	83	79	64	71	0.5

Table 5. Comparison between calculated and measured hip adduction strength (per cent) in 7 patients who had lost various hip adductors (for abbreviations see Table 1)

No.	Loss of muscle(s) tested	Calculated strength (%) for adduction from –50° to 0°	Measured isometric adduction strength (%) –30°	–15°	0°	Measured isokinetic adduction strength (%) 30°/s	90°/s	180°/s	Follow-up time (yrs)
10	AL	88	111	105	100	97	122	100	7
11	AL+AB+St	75	79	73	55	87	98	62	4
12	AL+AB+Pe	75	83	56	68	73	95	90	7
13	AL+AM	58	66	78	84	–	–	–	1.5
14	AL+AB+AM	49	36	24	21	52	21	–	1.5
15	AL+AB+AM	49	31	36	34	44	57	14	1.5
16	AL+AB+AM	49	32	26	20	34	8	0	1

maining abductor muscle or muscles seems to have occurred. Thus, in the two patients (6, 7) who had undergone the most extensive resection of abductor muscles, the measured abduction strength was more than twice as good as the calculated value in the neutral position of the joint, and in one of them (7, Figure 2), who had only the rectus femoris and sartorius left as abductors, the measured strength was three times as good as the calculated value when the hip was abducted 30°.

Hip adduction strength. Several muscles around the hip joint can act as adductors beside their primary function, e.g. the gluteus maximus via its femoral insertion. These muscles are responsible for the adduction when all three prime adductors (longus, brevis and magnus) have been removed. According to the values of Fick (1911), the strength for adducting the hip from 50° of abduction to the neutral position would theoretically be reduced to 49 per cent after extirpation of these muscles (Table 5). However, in the three patients (14, 15, 16) who had lost the adductor longus, brevis, and magnus, the adduction strength was about 20 per cent below this value, which may mean that these muscles actually contribute more to adduction strength than calculated from the experiments of Fick. Despite the low adduction strength, these patients had only slight or moderate impairment of function. The patient (10) who had lost the adductor longus alone had no loss of strength and no impairment of function.

Hip extension strength. Based on lever arms measured on cadavers and the cross-sectional area of the gluteus maximus, Pohtilla (1969) calculated that this muscle is responsible for 13–18 per cent of the hip extension strength. In the three patients who had lost the whole gluteus maximus, the isometric strength reduction varied between 0 and 22 per cent and the isokinetic strength reduction between 1 and 34 per cent. Our results agree fairly well with Pohtilla's measurements but less well with those of Fick (1911). Calculations based on his values make the gluteus maximus responsible for 45 per cent of the hip extension strength. If this figure is correct, the low reduction of the extension strength found in our patients after removal of the whole gluteus maximus would indicate that other muscles capable of extending the hip joint had hypertrophied. Among such other muscles are the hamstrings.

According to Pohtilla (1969), the semitendinosus is responsible for 7–9 per cent, the biceps femoris for 14–16 per cent, and all the hamstrings for 50 per cent of the hip extension strength. As the adductor magnus is responsible for 30 per cent, the removal of this muscle along with all the hamstrings would theoretically reduce the hip extension strength by 80 per cent. Our four patients who had lost the semitendinosus alone showed no strength reduction at all, whereas the two patients who had lost the biceps femoris alone showed a strength reduction in fairly good agreement with Pohtilla's estimation; however, the patient who had lost all the hamstrings had about 25 per cent and the patient who had also lost the adductor magnus about 30 per cent less strength reduction than calculated theoretically. Waters et al. (1974) measured hip extension strength at different pelvofemoral angles after sciatic nerve block in ten subjects. They estimated that the three hamstrings are responsible for 31–48 per cent of the hip extension strength. The low strength reduction, even in comparison with their values, in our patient who had lost all the hamstrings (26 per cent isometrically, 20 per cent isokinetically) may be due to a compensatory hypertrophy of the remaining extensors of the hip, the adductor magnus and gluteus maximus. And hypertrophy of the latter may be responsible for the relatively low strength reduction (41 per cent isometrically, 54 per cent isokinetically) in the patient who had also lost the adductor magnus as a hip extensor.

Knee extension strength. No particular pattern could be discerned in the strength reduction relative to which of the four different parts of the quadriceps that had been removed. This is in agreement with the concept that no separate function can be attributed to the different parts of the quadriceps (Lieb & Perry 1968, 1971). Regardless of which part was missing, the reduction of the knee extension strength was most pronounced at angles at which the greatest torque is normally produced (60 and 90°). Katz (1952) made the same observation after patellectomies and Mendler (1969) also pointed out that, after injury, the greatest strength reduction usually occurred at the angles of the greatest force.

The combined removal of the rectus femoris and the vastus medialis or vastus lateralis resulted in less reduction of the isometric knee extension strength than the combined removal of half of the vastus intermedius and the vastus medialis or vastus lateralis (22 versus 31 per cent). The low additional strength reduction when the rectus femoris had been included in the resection may partly be explained by the fact that the measurements were made in the seated position, which reduced the length and hence the tension of the muscle. This explanation would also apply to the relatively low strength reduction recorded when the rectus femoris had been removed alone. According to Fick (1911), the contribution of the rectus femoris to knee extension strength is 16 per cent when calculated with respect to leverage and the physiological cross-sectional area of the quadriceps. The mean strength reduction in our two patients who had lost the rectus femoris alone as a knee extensor was somewhat less (11.5 per cent; 9.5 per cent isometrically, 13.5 per cent isokinetically). Removal of the whole vastus intermedius in addition to the vastus medialis caused a pronounced reduction of the knee extension strength. According to Lieb & Perry (1968), the vastus intermedius is the most efficient part of the quadriceps because of its position and fiber direction.

When more than three quadriceps muscles have to be removed it seems worthwhile to increase the efficiency of the tensor fasciae latae as a knee extensor by transferring its tendon, the iliotibial band, to the quadriceps tendon (normally this muscle is a very weak knee extensor and functions as such only near full extension of the joint). The patient who had undergone transfer of the tensor fasciae latae had twice as good isometric knee extension strength as the other two patients who had lost more than three quadriceps muscles (44 versus 24 per cent; Figure 7 bottom).

In the quadriceps group, the reduction of knee extension strength was greatest when measured isokinetically, especially at high angular velocities. Thus, for knee extension, static strength was less affected. The reverse was true for the hip flexion strength when the rectus femoris had been removed and for the knee flexion strength when the semitendinosus or biceps femoris had been removed. Thus, for hip and knee flexion, dynamic strength was less affected.

Knee flexion strength. According to Fick (1911), the three hamstring muscles are together responsible for 88 per cent of the knee flexion strength and the sartorius and gracilis for the remaining 12 per cent. However, he did not take into account the gastrocnemius and popliteus as knee flexors. In our three patients who had lost all the hamstrings the mean reduction of the knee flexion strength was less than the theoretical value both isometrically (67 per cent) and isokinetically (63 per cent). A plausible explanation is that not only the sartorius and gracilis but also the gastrocnemius and popliteus remained as knee flexors.

According to Fick (1911), the semitendinosus is responsible for 29 per cent of the knee flexion strength. In our four patients who had lost this muscle alone, the mean strength reduction was somewhat less than this value isometrically (24 per cent) and considerably less isokinetically (6 per cent). The semitendinosus appears to increase in importance as a knee flexor with increasing flexion of the joint. At 30° the isometric strength reduction was barely 10 per cent, whereas it was 40 per cent at 90°. Of the hamstrings, the semitendinosus has the most distal insertion and therefore its lever increases most with increasing flexion of the joint. This may be the reason for the increasing importance of this muscle during knee bending. The biceps femoris is according to Fick (1911) responsible for 22 per cent of the knee flexion strength. In our three patients who had lost this muscle alone, the mean strength reduction was somewhat greater isometrically (28 per cent) and somewhat less isokinetically (18 per cent) than the theoretical value.

To sum up, the investigation has shown that removal of a single hip or thigh muscle does not cause any significant loss of function and that the functional impairment after removal of several muscles will to a large extent be compensated for by hypertrophy of remaining muscles with the same function. Even extensive loss of hip and thigh muscles is preferable to amputation, providing, of course, that the malignant tumor occasioning the operation is radically removed. In general, the functional impairment was less than would be expected from the strength reduction. But then it should be remembered that the remaining strength after muscle loss was determined relative to the maximal strength on the non-operated side. In daily life maximal strength is seldom needed for movements in the hip and knee joints.

CONCLUSIONS

1. Loss of the iliopsoas caused only slight impairment of function and little reduction of the hip flexion strength; the strength reduction became greater, however, with increasing flexion of the joint.
2. Loss of the tensor fasciae latae affected hip abduction strength somewhat more than hip flexion strength and resulted in a positive Trendelenburg sign. This sign was negative after extirpation of the gluteus maximus, which, like the tensor fasciae latae, acts as a hip abductor via its insertion in the iliotibial band.
3. Loss of the gluteus medius in addition to the abducting part of the gluteus maximus resulted in a positive Trendelenburg sign but the impairment of function was only slight. Disregarding a pronounced Trendelenburg gait, the function was good even when all hip abductors except the abducting part of the gluteus maximus or the rectus femoris and sartorius had been removed.
4. The three prime adductors (longus, brevis and magnus) are probably more important for the hip adduction strength than is indicated by theoretical calculations. However, loss of all of them caused only slight or moderate impairment of function.
5. Loss of the gluteus maximus had little influence on the hip extension strength and caused no impairment or only slight impairment of function. Significant strength reduction was seen only when all the hamstrings had been removed.
6. Reduction of the knee extension strength by less than 50 per cent caused only a slight impairment of function. This usually resulted from removal of one, one and a half, or two quadriceps muscles.
7. The reduction of knee extension strength was greatest in that part of the movement's range in which the torque normally has its maximum; the reduction became less pronounced the more the knee was extended.
8. Loss of quadriceps muscles did not reduce the range of active knee extension.
9. Loss of the vastus medialis or lateralis did not result in abnormal movement of the patella during extension and flexion of the knee.
10. Loss of a single hamstring muscle did not impair function significantly.
11. Loss of all the hamstrings reduced the knee flexion strength considerably but allowed fairly good function (moderate impairment).
12. Loss of quadriceps muscles decreased the isokinetic strength more than the isometric strength, whereas loss of hamstrings tended to reduce the isometric strength most.
13. The functional impairment was well compensated for and only one of the 46 patients had changed his occupation after the operation.

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