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PASSIVE RESISTANCE OF THE HUMAN KNEE: THE EFFECT OF REMOBILIZATION

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ABSTRACT

Changes of circumferential dimensions and passive resistance of the human knee caused by immobilization, were studied during remobilization. Patients immobilized with a long leg cast after tibial fractures or ligamentous injuries were studied immediately after removal of the cast and after mean periods of 18, 36 and 81 days of remobilization. Immobilization resulted in a decrease of circumferential dimensions. The difference in mid-thigh circumference between the immobilized and the unaffected leg was still present after 81 days of remobilization both for the patients with tibial fractures and for the patients with ligamentous lesions. An increase of midpatellar circumference was present exclusively in the patients with ligamentous lesions at all four testing dates, indicating that this is an effect of the ligamentous lesion and not of immobilization per se. *Variables of the hysteresis diagrams, resulting from sinusoidal movement of the knee at a range of knee angles, were used to quantify passive resistance of the knee in the flexion–extension plane (the muscles crossing the knee are inactive). Variables related to the elastic storage and release of energy, and variables related to energy dissipation were discerned. During remobilization the increased resistance to flexion (shown by the variables related to the elastic storage of energy), as found immediately after removal of the cast, disappears and the resistance becomes identical to the resistance of the unaffected leg. This may indicate a rapid readaptation of the length of ventral structures (shortened due to immobilization in a shortened position) to almost normal values. The variables related to energy dissipation, which do not differ between the two legs immediately after immobilization, are low in comparison with the unaffected knee during the whole remobilization period studied, indicating a remaining atrophy (as is also shown by the still decreased circumference of the lower limb). All resistance variables are still lower at the last date of testing when the knee is extended. The remobilization period studied was not long enough to achieve complete restoration of the dimensions of the lower limb and full return of normal passive resistance of the knee.*

Keywords: Passive resistance, sinusoidal movements, knee joint, immobilization, remobilization

INTRODUCTION

Many animal experiments have been performed with the aim of quantifying the influence of immobilization on the morphological, physiological, histochemical and mechanical properties of structures contributing to the functioning of joints[1,2].

Less is known of the changes taking place during remobilization, the period following immobilization. For Rhesus monkeys Noyes[3] has shown that the time needed to overcome changes in the mechanical properties of tibia–anterior cruciate ligament–femur preparations, caused by an immobilization period of 8 weeks, is 12 months. However, the recovery of muscles will be much faster than the recovery of periarticular tissues[4], as muscles adapt rapidly to changing circumstances[5].

It seems likely that changes during remobilization are related not only to the duration of the remobilization period itself, but also to the duration of the immobilization period; it is the latter which will determine the severity of conditions at the start of remobilization. Quantification of the influence of the duration of both periods on passive resistance of the knee during remobilization was the aim of this investigation.

The influence of immobilization on passive resistance of the knee has been described previously[6], here we deal with changes taking place in passive resistance of the knee during remobilization, for almost the same group of patients as that studied earlier[6].

METHODS

Patients

Two groups of patients participated: (a) 17 (14 males and 3 females) with a tibial fracture and (b) 21 (18 males and 3 females) with an incomplete rupture of the medial collateral ligament (12), lateral collateral ligament (2), the anterior cruciate ligament (3), the posterior cruciate ligament (1), the tendon of the quadriceps muscle (1) or a combination of several ligamentous structures (2). The patients with a tibial fracture will be referred to as 'fracture' group and the patients with ligamentous lesions as 'lesion' group. All patients were treated with a long plaster cast with the knee in slight flexion (10° to 20°) (0° corresponds to full extension of the knee), for periods between 28 and 142 days.

Thirty-one patients (12 with tibial fractures and 19 with ligamentous injuries) were measured within 3 h of the removal of the cast (the results of these measurements represent the influence of immobilization[6]). During remobilization the patients were subjected 3 times to an identical measuring procedure based on the duration of the remobilization period up to the date of testing. Measurements were performed more than 3 h but less than 28 days after removal of the cast, within a period of 29 to 48 days, and

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Table 1 Mean and standard deviation (s.d.) of the immobilization period, remobilization period, age and body weight for the fracture and the lesion groups

	Test date	Fracture group			Lesion group			*d*
		n	mean	s.d.	*n*	mean	s.d.	
Immobilization period (days)	1	12	106	27	19	46	11	*
	2	10	90	36	17	43	9	*
	3	11	93	29	10	50	13	*
	4	10	94	33	9	49	14	*
Remobilization period (days)	1	—	—	—	—	—	—	—
	2	10	19	5	17	17	5	—
	3	11	36	5	10	37	10	—
	4	10	81	28	9	80	40	—
Age (years)	1	12	29.5	15.5	19	34.6	15.7	—
	2	10	27.3	14.3	17	31.4	14.0	—
	3	11	25.6	11.8	10	35.2	15.6	—
	4	10	28.7	16.3	9	44.9	16.3	—
Body weight (kg)	1	12	65.4	9.9	19	73.7	16.2	—
	2	10	64.4	10.7	17	71.0	10.5	—
	3	11	66.5	10.1	10	71.7	16.9	—
	4	10	66.7	10.3	9	72.3	18.7	—

An asterisk indicates a significant difference (Wilcoxon-Mann-Whitney) between the groups

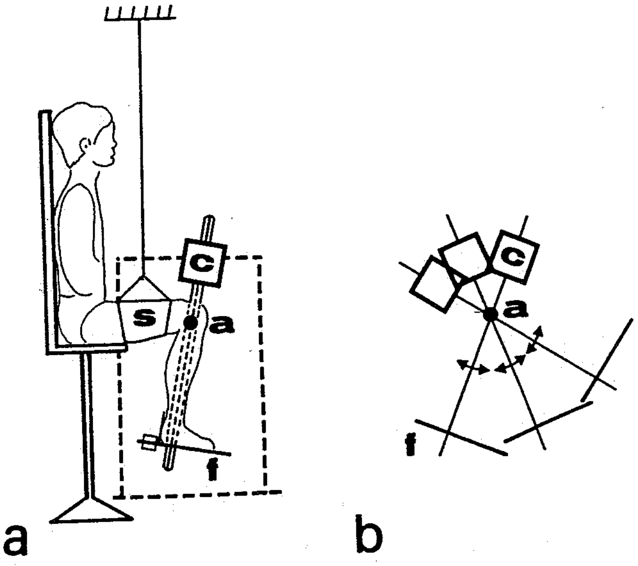

Figure 1 Vertical knee arthrograph. **a**, Schematic lateral view of the apparatus and subject. a, horizontal axis of rotation of the drive arm; f, adjustable footplate; s, sling used to suspend the thigh. **b**, Three positions of the drive arm; arrows indicate the sinusoidal excursions

more than 48 days, after removal of the cast. The results of the measurements taken during remobilization represent the influence of immobilization as well as remobilization. All patients received physiotherapy treatment during remobilization; no attempt was made to quantify either the quality of that treatment or the daily activities of the patients. Mean age, body weight and the length of immobilization and remobilization period are shown in *Table 1*.

For all patients several anthropometric measurements, necessary for the positioning of the patients in the apparatus and for the quantification of the influence of immobilization and remobilization on the dimensions of the lower limb, were performed. These include: mid-thigh circumference, maximal calf circumference, length of the upper and lower leg, foot length, body length, and skinfold thickness at the anterior side of the thigh and the medial side of the calf[7]. The skin temperature at the medial side of the knee was measured with a digital thermometer (WM I, ITT Instruments).

Apparatus

The apparatus, the positioning of the subjects and the variables of the moment–angle diagrams have been described in previous papers[6,7]; only a summary will be given here.

By means of a vertical knee arthrograph (*Figure 1*), the passive moments of the knee during sinusoidal excursions in the flexion–extension plane were recorded for a wide range of knee angles. Passive moment is due to deformation of all tissues which cross the joint, provided that the crossing muscles are inactive[8]. Frequency and amplitude of movement were kept relatively low (0.082 Hz and 7.5° respectively) in order to minimize the effects of inertia and to facilitate relaxation of the muscles crossing the knee. Moment and angle of the drive arm of the arthrograph were recorded simultaneously, yielding moment–angle (hysteresis) diagrams.

Procedure and resistance variables

For all patients a series of diagrams was produced during each session (*Figure 2*). Because muscle relaxation is enhanced by a fixed order of measurement and the position and shape of the moment–angle diagrams are influenced by the order of measurement[7], fixed order measurements were used, in the transition from flexion to extension.

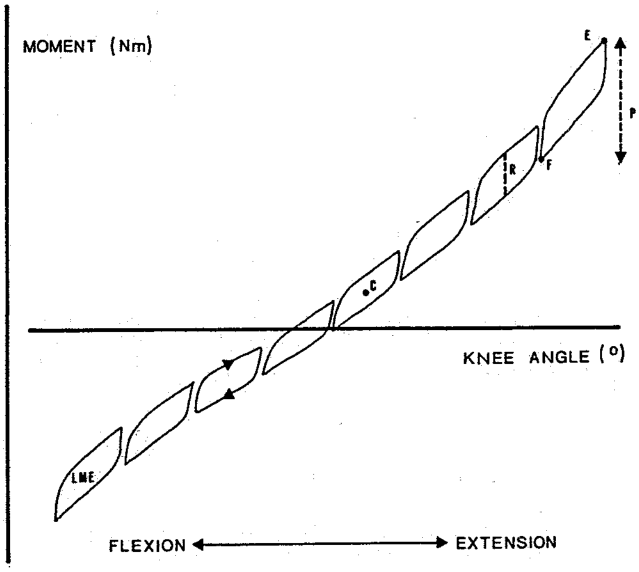

Figure 2 A series of moment-angle diagrams and their variables. For all diagrams several variables were determined, including: C, centre moment; LME, loss of mechanical energy; E, extension moment; F, flexion moment; P, peak-to-peak moment; and R, centre range

For the unaffected leg recording started at a knee angle of approximately 105°; full extension was avoided during the measurements and each registration was checked for absence of possible muscle activity (disturbances of the diagrams are present as soon as EMG-activity can be detected with surface electrodes[7]). A moment–angle diagram was drawn for every 5° to 7.5° decrease of knee angle, this yielded 15 to 20 diagrams for the unaffected knee. Since immobilization limits the flexion range of the knee and induces pain when the knee is flexed, diagrams were drawn only in the range where pain was absent, to avoid unwanted muscle contractions. However, the limitation of flexion was restored rapidly during remobilization. Immediately after immobilization, recording started at 60° of flexion for most patients, but within a few weeks of remobilization it was possible for the majority to flex the knee passively, without pain, to more than 112.5°, an angle necessary to record a diagram with a centre angle of 105° and an amplitude of movement of 7.5°.

Three absolute and three relative variables were used to characterize the moment–angle diagrams. The absolute variables were (*Figure 2*): centre moment (*C*); peak-to-peak value (*P*), (defined as extension moment (*E*) minus flexion moment (*F*)[9]); and area of the diagram, representing the loss of mechanical energy (*LME*)[10]. Relative variables, calculated with the aid of the absolute variables: dynamic elastic stiffness (*DES*) (defined as *P* times the cosine of the phase lag between angle and moment divided by twice the movement amplitude[11]); dynamic viscous stiffness (*DVS*) (defined as *P* times the sine of the phase lag divided by twice the movement amplitude[11]); and loss tangent (*LT*) (defined as *DVS* divided by *DES*[12]). The sine of the phase lag between angle and moment is defined as the centre range of the diagram (*R*) divided by *P*[11].

In addition to dynamic measurements, static measurements also were taken; 2–5 s after positioning the knee the moment was recorded.

Data processing

By convention, positive moments are registered if the knee is extended, and negative moments if it is flexed. Consequently positive moments are caused by stretching structures located dorsally to the flexion–extension axis of the knee and negative moments by stretching structures located ventrally to that axis.

Static-, flexion-, centre- and extension moments of each knee were fitted (least square) with a cubic function (*Figure 3a*). For all patients the values of these curves were calculated at several positions: a knee angle of 15°, 30°, 45°, 60°, 75°, 90° and 105° of flexion. The knee angle yielding zero centre moment is called 'dynamic equilibrium angle'; the angle yielding zero static moment 'static equilibrium angle'.

Since stretching a biological material can be described by an approximately exponential increase in force[13]; static, flexion, centre and extension moments were fitted by two exponential curves, one for the moments recorded when the knee angle was (minimally 5°) less than the equilibrium angle and one when the knee angle was (minimally 5°) more than the equilibrium angle (*Figure 3b*)[7]. Based on these curves the moments were approximated at angular deviations of 15°, 22.5°, 30° and 37.5° above and below the equilibrium angle. As in the immobilized knee immediately after immobilization, the number of data points above and below the equilibrium angle separately was too small in the immobilized knee for reliable exponential fitting, moments at angular deviations of 7.5°, 15° and 22.5° above and below the equilibrium angle were calculated from the corresponding cubic functions.

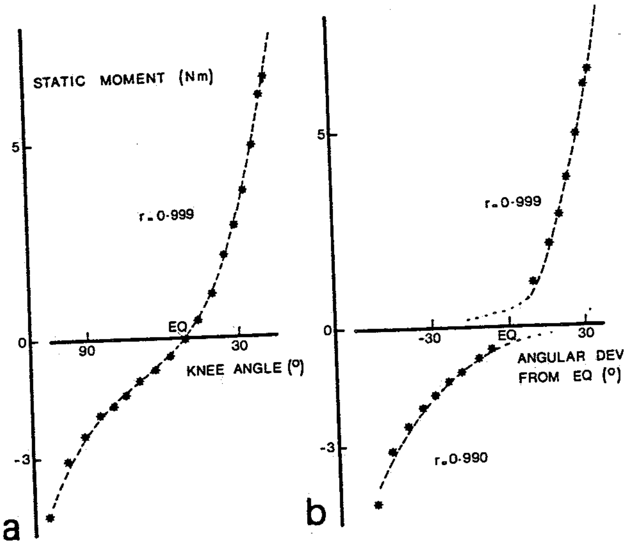

Figure 3 Example of the relation of static moments and knee angles, in one of the patients, fitted by a cubic function, a, and with two exponential curves, b. Part of the exponential curves indicated by a dotted line is obtained by extrapolation. The original data points are indicated by stars

P values were calculated with the aid of the fitted curves for extension and flexion moments at given knee angles, as well as at given angular deviations from the equilibrium angle. *LME* and *R* at these angles were obtained by linear interpolation between two adjacent data points. The relative variables *DES*, *DVS* and *LT* at these angles were calculated from the values of *P*, *R* and movement amplitude.

The unaffected leg is used as a control; this may have resulted in an under or overestimation of the values for the immobilized leg, in those cases when the unaffected leg also is influenced by the process of immobilization and remobilization. For example, Burri and Helbing[14] have found a decrease in thigh circumference in both legs due to pre-operative disuse in patients with ligamentous lesions in one of the legs. To test whether changes take place during remobilization in the unaffected leg, mid-thigh circumference and static moments and variables of the moment–angle diagrams at 15° and 105° of flexion were tested for sequential differences in the unaffected leg of 12 patients measured at date 1, 2 and 3, using the Wilcoxon-Wilcox test. As only one significant value was found (SM at 15° of flexion was significantly lower at date 1 compared to dates 2 and 3) ($p < 0.05$), the use of the unaffected leg as control was considered admissible. However, changes in the unaffected leg during the immobilization period could not be excluded on the basis of our data.

Statistics

Nonparametric tests were used in this study to test differences between the immobilized and the unaffected knee (Wilcoxon), differences between the two groups of patients (Wilcoxon-Mann-Whitney), differences within each group with increasing remobilization period (Wilcoxon-Mann-Whitney), and correlations between the length of the immobilization and remobilization periods with changes of passive resistance and anthropometric variables (Spearman)[15].

For all tests a level of significance of 5% was chosen.

RESULTS

As can be seen from *Table 1*, age, body weight and remobilization period did not differ for the patients of either the fracture or the lesion group at the different dates of testing. However the immobilization period was longer for the fracture-group.

The anthropometric variables are summarized in *Table 2*. To reduce the number of variables and to facilitate comparison between the two groups of patients, differences between the immobilized and the unaffected leg were calculated as a percentage of the corresponding value in the unaffected leg for each patient separately, negative indicating lower and positive, higher values for the immobilized leg. Only the difference in skin temperature between the immobilized and the unaffected leg is shown as an absolute difference (in °C). The reduction in mid-thigh and calf circumference between immobilized and unaffected legs, both with and without correction for skinfold thickness, still exists after more than 2.5 months of remobilization for the patients of the fracture-group (*Table 2*). The same is true for the patients of the lesion-group with the exception of fat free maximal calf circumference.

When the patients of the fracture and lesion groups are compared, the reduction of mid-thigh circumference, both corrected and uncorrected for skinfold thickness, is higher for the former at test dates 1 and 2. At the fourth test date only the fat free mid-thigh circumference is higher for the patients of the fracture group. The stronger reduction of thigh circumference for these patients can be explained by the longer immobilization period compared to that of the patients in the lesion group (*Table 1*). For the changes of calf circumference less consistent results were found (*Table 2*).

Table 2 Mean and standard deviations (s.d.) of differences between the immobilized and the unaffected leg in anthropometric variables within the tibial fracture group and the lesion group separately

Differences between the immobilized and the unaffected leg	Test date	Fracture group				Lesion group				Difference T–L
		n	mean	s.d.	*d*	*n*	mean	s.d.	*d*	
Mid-thigh circumference (%)	1	12	−8.2	4.0	*	18	−3.7	3.4	*	*
	2	10	−7.5	2.8	*	17	−4.4	3.4	*	*
	3	11	−7.6	3.0	*	10	−5.0	1.6	*	—
	4	10	−5.5	3.2	*	9	−3.1	1.7	*	—
Fat free mid-thigh circumference (%)	1	12	−9.6	3.4	*	17	−4.2	3.9	*	*
	2	10	−8.9	2.8	*	16	−5.1	3.9	*	*
	3	11	−8.2	3.5	*	8	−6.3	2.3	*	—
	4	9	−6.7	2.7	*	7	−3.0	2.1	*	*
Midpatellar circumference (%)	1	12	−0.4	3.2	—	19	2.5	2.8	*	*
	2	10	1.6	3.1	—	16	3.6	3.0	*	—
	3	10	1.1	2.0	—	10	3.9	2.4	*	*
	4	10	−0.2	1.8	—	9	2.3	2.1	*	*
Maximal calf circumference (%)	1	10	−3.1	4.2	—	18	−1.5	3.1	*	—
	2	8	−1.8	2.9	—	16	−0.1	2.6	—	—
	3	11	−3.5	3.4	*	9	−0.9	1.1	*	*
	4	10	−3.1	4.1	*	9	−1.4	2.2	—	—
Fat free maximal calf circumference (%)	1	8	−9.8	4.9	*	18	−3.5	2.7	*	*
	2	5	−3.1	4.5	—	16	−0.7	2.6	—	—
	3	10	−6.3	4.2	*	9	−1.0	4.0	—	*
	4	9	−4.7	4.2	*	8	−2.8	2.2	*	—
Skin temperature (°C)	1	10	0.6	1.7	—	17	1.4	1.2	*	—
	2	10	1.5	1.5	*	17	1.4	0.7	*	—
	3	10	1.4	1.1	*	9	1.9	1.7	*	—
	4	8	1.0	1.0	*	9	1.4	1.3	*	—

The differences are expressed as percentage of the corresponding value in the unaffected leg. An asterisk indicates the presence of a significant difference (Wilcoxon) within each group of patients. The last column indicates whether these differences in anthropometric variables are identical for the tibial fracture (T) and the lesion (L) group. An asterisk indicates a significant difference (Wilcoxon-Mann-Whitney) between both groups

As an increased midpatellar circumference was found only for the lesion group, at all four dates of testing, this increase can be considered an influence of the ligamentous lesion and not of immobilization. Although skin temperature was the same in the immobilized and the unaffected leg for the fracture group immediately after immobilization, a significantly higher temperature was found at dates 2 to 4. For the lesion group, skin temperature was higher for the immobilized knee at all four dates of testing. Although both a rise in skin temperature and an increase in midpatellar circumference can indicate local hyperaemia and oedema or hydrops, this was not corroborated by the calculated correlations.

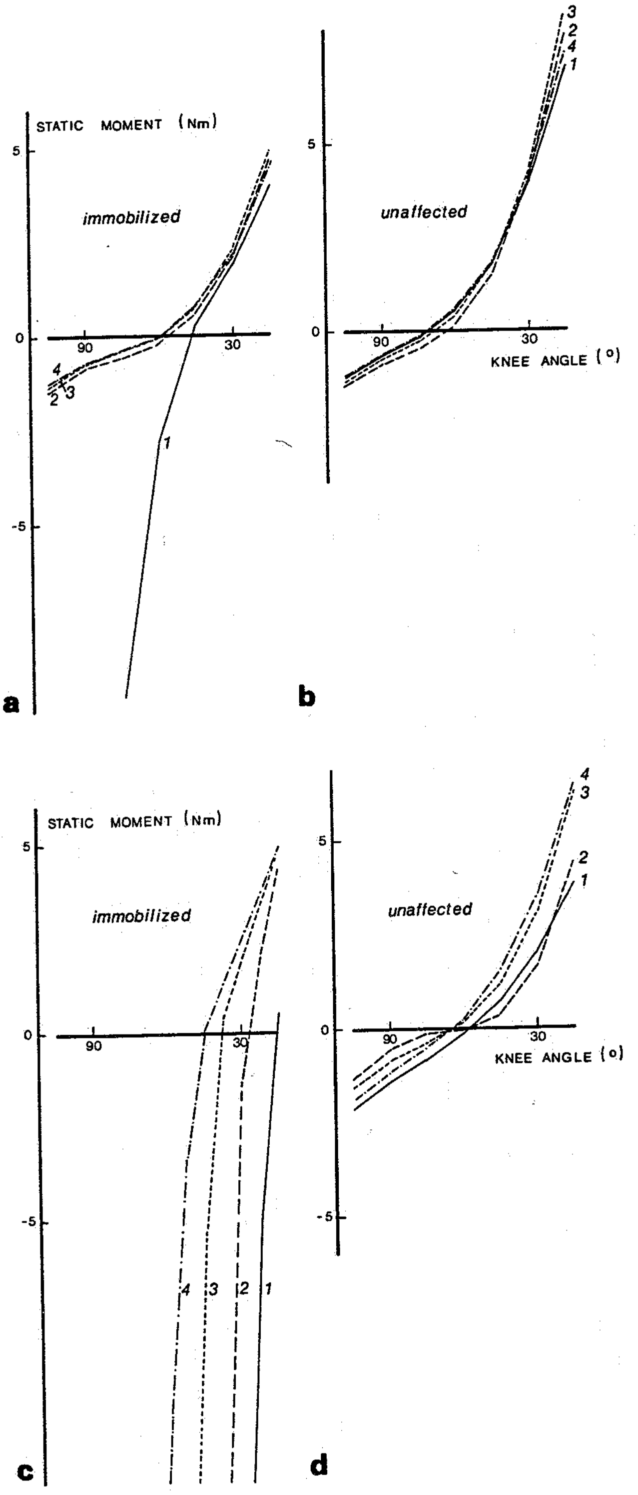

Figure 4 Examples of relations of static moments and knee angles for two patients of the lesion-group. a and b static moments of the immobilized and unaffected leg for a patient with a fast decrease of the resistance to flexion in the immobilized knee. c and d static moments of the immobilized and unaffected leg for a patient with a remaining high resistance to flexion in the immobilized knee. 1, 2, 3 and 4 the date of testing

Changes taking place in passive resistance to movement of the knee during remobilization vary considerably between patients. In *Figure 4* examples are given for two patients of the lesion group, both measured four times. The increased resistance to flexion immediately after immobilization disappeared rapidly for one of the patients (*Figure 4a and 4b*). The other patient complained more of pain and stiffness. The passive resistance to knee flexion of his affected leg remained high throughout the remobilization period (*Figure 4c*) compared to the controlateral limb (*Figure 4d*).

The inter-individual differences in the fracture-group were smaller, presumably because these patients had no lesion of the knee.

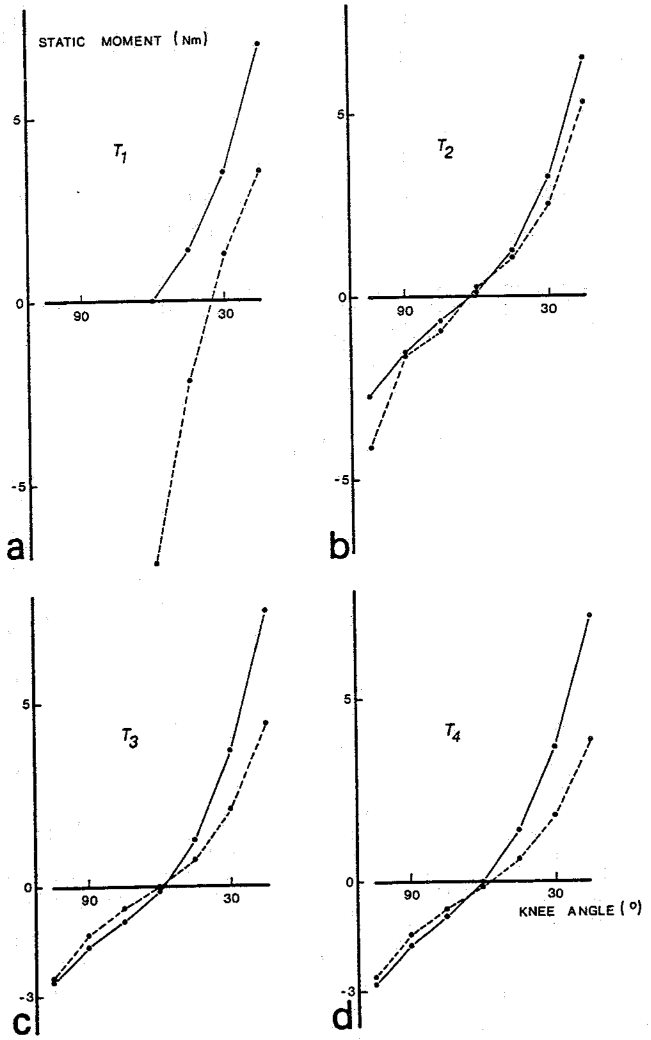

Figure 5 Relation of mean static moments and knee angle in the tibial fracture group at date 1 (T_1, a), date 2 (T_2, b), date 3 (T_3, c) and date 4 (T_4, d) at absolute knee angles. Standard deviations are not indicated. Static moments of the unaffected leg (——); of the immobilized leg (– – –)

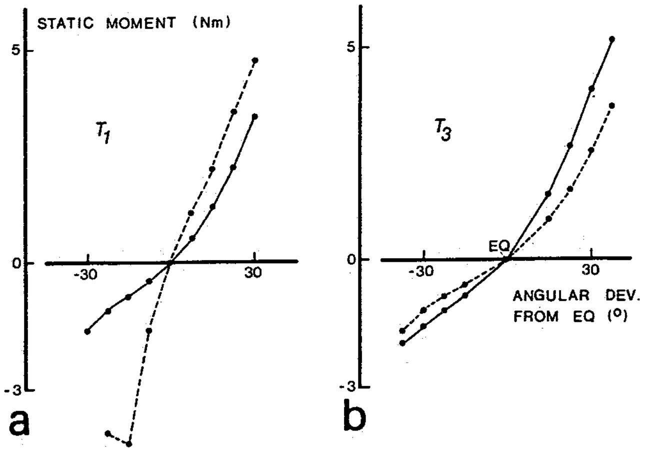

Figure 6 Relation of mean static moments and angular deviations from the equilibrium angle (EQ) in the tibial fracture group at date 1 (T_1, a), and date 3 (T_3, b). Standard deviations are not indicated. Static moments of the unaffected leg (—); of the immobilized leg (– – –)

In *Figure 5* static moments are presented as a function of knee angle at the four different dates of testing for the fracture group. The static moments at angular deviations from the equilibrium angle are shown for the fracture group at test dates 1 and 3 in *Figure 6*. *DES*, *DVS* and *LT* as a function of knee angle are represented in *Figure 7* at all four testing dates. To facilitate comparison between the dates, *DES*, *DVS* and *LT* are expressed as a percentage of their value at the corresponding knee angle in the unaffected leg; the values of the unaffected leg are thus represented by a horizontal line at 100% (*Figure 7*).

Absolute differences between immobilized and unaffected leg in variables of the moment–angle diagrams were shown to be identical for both the fracture and the lesion group during remobilization at each date of testing (Wilcoxon-Mann-Whitney). Subsequently, these data were pooled to test differences between immobilized and unaffected leg in variables of the moment-angle diagrams (*Table 3*). Note, that when the knee is extended (to either a knee angle of 15° or to an angular deviation of 30° below the equilibrium angle), the values of the immobilized leg are identical to or smaller than those of the unaffected leg, with the exception of *P* immediately after immobilization and *LT* at test date 2 and 3. When the knee is flexed (to 105° or to 15° above the equilibrium angle), higher values were often found for the variables related to the elastic storage and release of energy (*C*, *P* and *DES*) at the first three testing dates (*Table 3*). The variables related to energy dissipation (*LME* and *DVS*) are lower in the immobilized leg when the knee is flexed from the second date of testing. Immediately after immobilization the flexion range is limited, no data are therefore available at test date 1 on the influence of immobilization on passive resistance at a knee angle of 105°.

DISCUSSION

Anthropometric variables

The decrease of mid-thigh circumference as found for the patients with tibial fractures after a mean immobilization period of 15 weeks (8.2%; *Table 2*), is comparable with the decrease of 9.0% found by Rosemeyer and Stürz[16] after 12 weeks of immobilization. The decrease in fat free mid-thigh circumference is greater than mid-thigh circumference (Wilcoxon) (*Table 2*) due to a significant increase of skinfold thickness after immobilization. The difference of mid-thigh circumference after 36 days of remobilization was not statistically different from the difference found immediately after immobilization; this agrees with the finding of Rosemeyer and Stürz[16] that in the first 6 weeks of remobilization, circumference does not increase. Their finding that a remobilization period of twice the duration of the immobilization period is necessary for a return of the circumference to normal values, could not be checked in our study; the time for which the fracture group participated was too short. For the lesion group (mean immobilization period of 46 days) a remobilization period of 80 days was not sufficient for recovery of thigh circumference of the immobilized leg (*Table 2*).

Although the reduction in thigh circumference is most prominent during the first 6 weeks of immobilization and decreases afterwards[16], those patients with tibial fractures show a significantly greater decrease in thigh circumference than patients with ligamentous lesions. However, within 37 days of remobilization this difference disappeared.

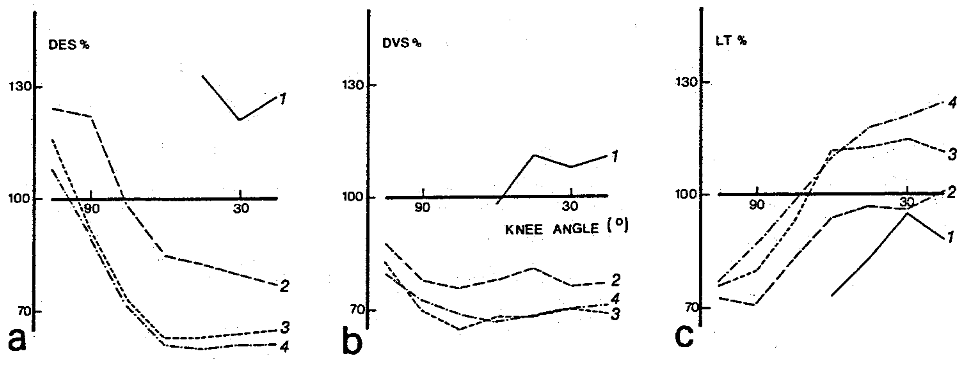

Figure 7 Mean dynamic elastic stiffness (DES), a; Dynamic viscous stiffness (DVS), b; and loss tangent (LT), c, of the immobilized leg as percentage of their corresponding value in the unaffected leg for the tibial fracture-group at all four dates of testing

Table 3 Influence of immobilization and remobilization on variables of the moment–angle diagrams in flexion and extension at all test dates

	Flexion								Extension							
	Angle of 105°				Ang. dev. from ea. of 15°				Angle of 15°				Ang. dev. from ea. of 30°			
Variable	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
SM (Nm)	—	=	=	=	>	=	>	=	<	<	<	<	>	=	<	<
C (Nm)	—	=	=	=	>	=	>	=	<	<	<	<	=	=	<	<
P (Nm)	—	>	>	=	>	=	>	=	=	<	<	<	>	=	=	<
DES (Nm/°)	—	>	=	=	>	=	>	=	=	<	<	<	=	=	=	<
LME (Nm/°)	—	<	<	<	=	<	<	<	=	<	<	<	=	<	<	<
DVS (Nm/°)	—	<	<	=	=	<	<	<	=	<	<	<	=	<	<	<
LT (—)	—	<	<	<	<	<	=	<	<	=	=	=	>	=	=	=

The knee is flexed to a knee angle of 105° or to an angular deviation of 15° above the equilibrium angle and extended to an absolute knee angle of 15° or to an angular deviation of 30° below the equilibrium angle. The data of the fracture and lesion groups are pooled. 1, 2, 3 and 4 indicate the testing date. —, at that angle measurements were impossible; <, a significantly lower value in the immobilized leg compared to the unaffected leg; >, a significantly higher value in the immobilized leg compared to the unaffected leg; =, the value of the immobilized and the unaffected leg did not differ (Wilcoxon). SM, static moment; C, centre moment; P, peak-to-peak moment; DES, dynamic elastic stiffness; DVS, dynamic viscous stiffness; LT, indicates loss tangent; and ea. equilibrium angle

Passive resistance

The contribution to its passive resistance of each of the knee's separate structures, is a function of strain (or actual length), internal arrangement (architecture), external dimensions, the lever arm and its material[17].

During immobilization of a joint there are two major changes which influence its passive resistance. First there is an adaptation of the length of all the immobilized structures related to their length during immobilization[2,5], and second there is a change in cross sectional area of the immobilized structures.

Length adaptation. With respect to length adaptations it can be said in general, that structures immobilized in a shortened position show a decrease in absolute length, while structures immobilized in a lengthened position increase in length[2,5]. To determine whether a muscle is immobilized in a shortened or a lengthened state, its optimal length (the length at which a muscle can perform maximal active force[18]) is used as a reference. Due to changes of muscle length induced by immobilization, the passive length force curve of muscles changes: when the muscle is immobilized in a shortened position its fibres become shorter and consequently the curve moves to the left and becomes steeper[2]; when the muscle is immobilized in a lengthened position the curve moves to the right, while the slope remains either the same[19] or increases[2]. Based on the work of Tabary *et al.*[5], which indicates that the tibialis anterior muscle and the soleus muscle have their optimum angle at the same ankle angle, and assuming that passive resistance of muscles at the ventral and dorsal side of the knee is similar at their optimum angle, it was hypothesized that the equilibrium angle of the knee corresponds to the optimum angle of muscles at the ventral and dorsal side of the knee as well as to their optimum length (assuming variations in lever arm are negligible). The adaptation of length of muscles crossing the knee and the resulting changes of their passive length force curves may be used to explain changes of passive resistance found immediately after immobilization[6]. The length of muscles located ventrally to the flexion–extension axis of the knee, immobilized in a shortened position (the equilibrium angle of the unaffected leg is about 55° of flexion) is decreased and consequently the resistance to flexion is increased (*Figure 5*). The length of muscles located dorsally to the flexion–extension axis, immobilized in a lengthened position, is increased and consequently the resistance to extension is decreased when the resistance is compared at absolute knee angles (*Figure 5*). If the passive resistance of an immobilized and an unaffected knee is compared at given angular deviations from the equilibrium angle the resistance to both flexion and extension is significantly increased for *SM* and *P* only[6] (*Table 3*). Although the definition of a reference length for periarticular tissues is difficult[20], it is assumed that these structures show changes analogous to those in muscles[6].

Change of cross sectional area. The degree of atrophy caused by immobilization, is higher when the shortening of the structure during immobilization is more pronounced[21]; when a muscle is immobilized at a length above the optimum, atrophy as well as hypertrophy can take place[22].

Since atrophy of ventral structures occurs due to immobilization in a shortened position, the two major changes taking place during immobilization have opposite effects if the knee is flexed; atrophy decreases the resistance and reduction of length increases the resistance to flexion. As the resistance to flexion is increased immediately after immobilization it is concluded that the influence of shortening of the structures at the ventral side of the knee is dominant over the influence of atrophy of these structures.

In patients with ligament lesions, oedema, hydrops (resulting in an increase of intra-articular pressure during knee flexion[23]) and scar tissue (especially when this is located ventrally in the knee joint) may have caused part of the increase in passive resistance when the knee is flexed.

During remobilization a rapid decrease in passive resistance occurs when the knee is flexed (*Figure 5*).

At the last testing date the variables related to elastic storage and release of energy are identical to those of the unaffected leg (*Table 3*). This can be explained by a return of the length of immobilized structures to almost normal values. The lower values of variables related to energy dissipation (*LME* and *DVS*) from dates 2 to 4, when the knee is flexed, can be ascribed to atrophy which was still present at the last date of testing. A reduction of fat free mid-thigh and calf circumference found even after 2.5 months of remobilization is also compatible with this.

The resistance to extension at given knee angles is decreased in comparison with the unaffected leg at all testing dates. At an angular deviation of 30° below the equilibrium angle the resistance is increased immediately at the end of immobilization, but decreased afterwards (*Table 3*). As the remobilization period increases, the decrease in resistance to extension is more pronounced, as is shown by a negative coefficient of correlation between the duration of the remobilization period and *DES* and *DVS* in the immobilized leg (as a percentage of their corresponding value in the unaffected leg) at 15° of flexion (−0.53 and −0.42 respectively, both significant), based on the pooled data of the patients of the fracture group at all four dates of testing.

CONCLUSIONS

The high passive resistance of the knee to flexion immediately after removal of the cast, as shown by the variables related to elastic storage and release of energy, disappears during remobilization. At the last date of testing these variables are identical to those of the unaffected leg. The variables related to energy dissipation are still smaller at this last testing date, both during knee flexion and knee extension, indicating that the influence of atrophy becomes more prominent.

During remobilization, a relative readaptation of the length of immobilized structures (decreased for structures located at the ventral side of the knee and increased for the structures located dorsally) to almost normal values probably occurs. Atrophy disappears only slowly, as is shown also by the still smaller mid-thigh and maximal calf circumference after 2.5 months of remobilization.

A longer remobilization period than the 80 days used in this investigation must be studied to determine the duration of the period necessary for complete disappearance of atrophy and for return of passive properties comparable to those of the unaffected knee. Excessive loading of the knee should be avoided for more than 2.5 months.

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