

* Strength training and neuromuscular function in elderly people with total knee endoprosthesis

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The effects of 1 year of intensive strength training on neuromuscular function were studied in elderly people operated for total endoprosthesis ($n=30$) divided into 3 groups: training group 1 (TG1, $n=11$), training group 2 (TG2, $n=10$) and control group (CG, $n=9$). After the operation, TG1 and TG2 trained every second day and the training was controlled by training diaries, and CG performed only conventional exercises by themselves. The overall volume of training in TG2 was 30% greater than in TG1. Neuromuscular function was examined by measuring maximal electromyography (EMG) and maximum voluntary isometric and dynamic strength of the knee extensor and flexor muscles. The range of motion of the knee joint and the cross-sectional area (CSA) of the knee extensor muscles were also measured. After the preoperative tests, the same measurements were repeated 3, 6, 12, 24 and 52 weeks postoperatively. After the dramatic decreases in maximal isometric torque and EMG-activity during the first postoperative weeks in all groups, TG2 showed the most remarkable improvement in neuromuscular function. For instance, the maximum isometric extension torque measured at 90° knee angle increased between the 24th and 52nd weeks. The increase in the EMG-activity of the rectus femoris muscle was significant between the 12th and 24th weeks. The CSA of the knee extensor muscles in TG2 was greater 1 year after the operation compared with the preoperative value. The intra- and extra-articular swelling of the knee joint may have irritated the free nerve endings, leading to reflex inhibition with a concomitant decrease in EMG and strength of the knee extensor muscles. Because TG2 demonstrated the most remarkable improvement in neuromuscular function after the first postoperative weeks, intensive training programs can be successfully used in rehabilitation after a major knee operation, even in elderly people.

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greater volume of training

Key words: neuromuscular function; rehabilitation; electromyography; strength training; total endoprosthesis operation; elderly

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The influence of aging on the morphology and physiological characteristics of the skeletal muscle is relatively well documented. With increasing age the functional capacity and the strength of the muscle decrease (1). The decrease in muscle strength is related to the neural and morphological changes in the muscle, the vascular and endocrinological factors and the reduction in daily physical activity (2-5).

During aging, muscle strength decreases remarkably so that the strength of the knee extensors is about 30-40% lower in 70-year-old people than 30-year-old people (6-9). A short training period can increase muscle strength in elderly people when the stimuli of the training are sufficient (1, 3, 5, 10). According to the study of Frontera et al. (10), the strength of knee extensor muscles in elderly people

increased as much as 10-20% during an intensive training period of 12 weeks.

In addition to aging, detraining and inactivity lead also to a reduction in muscle strength and in the voluntary neural activation of the muscles. The magnitude and the time course of the reduction in muscle strength is influenced by the character and duration of the detraining period (11-16). The decrease in voluntary neural activation seems to be a major cause for the reduction in muscle strength in acute disuse of the trained muscles, and muscle atrophy contributes to the reduction during the later phases of detraining (11-17). During immobilization the reduction in muscle strength is dramatic. Muscle atrophy begins immediately after the operation and the rate of atrophy is great after the first postoperative week

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Table 1. F

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(18). Muscle atrophy is characterized by a reduction in the size of individual muscle fibers and an increase in the proportion of connective tissue (3, 19-23).

The degeneration of the knee joint reduces the functional capacity of aging people. The total knee endoprosthesis operation has proved to be an effective method to restore the functioning of the degenerative knee joint and to remove pain (24, 26). The recovery in strength of the knee extensor and flexor muscles is very important to optimize the functioning of the knee joint. In this process, strength training should therefore have an important role.

The purpose of this study was to examine the effects of intensive and prolonged strength training on muscle strength, neural activation and the cross-sectional area of the knee extensor and flexor muscles in elderly people operated for total knee endoprosthesis. The changes in the range of motion of the operated knee joint during this intensive rehabilitation period were also examined.

Material and methods

Subjects

Thirty-four patients who suffered from degenerative knee joint diseases (arthrosis deformans genu and arthritis rheumatoides) participated in this study. Each patient received total endoprosthesis of the knee. After the operation the patients gave their written consent to the volunteer in the study. The patients were randomly divided into 3 groups, training group 1 (TG1, $n=12$), training group 2 (TG2, $n=11$) and control group (CG, $n=11$). One patient in both training groups and 2 in the control group could not continue in the study after the operation due to complications. TG1 ($n=11$) consisted of 9 women and 2 men, TG2 ($n=10$) of 6 women and 4 men and CG ($n=9$) of 7 women and 2 men. The physical characteristics of the subjects are shown in Table 1. In the beginning of the study there were no significant differences between the 3 subject groups in age, height or weight.

Strength training

The patients in each group were treated by conventional physiotherapy methods (exercises to increase the ROM of the knee joint and to decrease edema

and strength training for the knee extensors using isometric actions) during the first 2 weeks after the operation. In addition to these exercises, the patients were treated by passive continuous motion (PCM) during the first postoperative week. On the third week the patients in the training groups began their intensive strength training. After a supervised training period of 1 week in the hospital, the patients continued to carry out the same training program at home. The entire follow-up period lasted for 1 year. The loading intensity in both training groups was the same, but the overall volume of strength training was considerably higher in TG2 than in TG1 (Table 2).

Both strength training programs consisted of isometric and dynamic exercises for the knee extensors and flexors. Altogether 2 isometric extension exercises and 1 isometric flexion exercise in 2 different angular positions (knee flexion at 60° and 90°) were performed in each training session. The isometric muscle actions were done supine and in a sitting as well as in a standing position against an unmovable resistance. The muscle contraction time for each maximum isometric muscle action was 5 s; the recovery time was 30 s between the muscle actions and 3 min between the sets. Dynamic extensions and flexions were performed for warming-up purposes before the isometric muscle actions in a sitting position without the extra load. The exercises and the amount of the muscle actions were changed every third month (Table 2). During the entire follow-up year the training program was performed every second day so that each training session lasted for 30-50 min, depending on the training period. The subjects in the 2 training groups marked their training on the training diaries so that the actual amount of the training could be analyzed (Table 2).

The conventional training program for the control group performed at home consisted of isometric knee extension exercises and of exercises to increase the ROM of the knee joint. However, in the control group the amount of training was not controlled after the patients were released from the hospital.

Measurements

Strength, electromyographic (EMG) and ROM measurements were performed by using the David Rehab System (David Fitness and Medical, Vantaa, Finland), which is a personal computer-compatible microcomputer-controlled device with real time data. The preoperative measurements were performed on 2 consecutive days immediately prior to the operation. The best values of these 2 preoperative measurements were used in the final analysis. Postoperatively the measurements took place 3, 6, 12, 24 and 52 weeks after the operation (Fig. 1). Only the operated knee was tested.

Table 1. Physical characteristics of the subjects in TG1, TG2 and CG (mean \pm SD)

Group	<i>n</i>	Age (years)	Height (cm)	Weight (kg)
TG1	11	67.5 \pm 5.7	162.5 \pm 5.9	73.5 \pm 9.7
TG2	10	67.0 \pm 6.0	167.2 \pm 10.8	79.1 \pm 14.6
CG	9	67.9 \pm 4.3	165.0 \pm 9.5	81.6 \pm 15.9

Table 2. The actual number of repetitions and sets performed in the exercises in the TG1 and TG2 during different training periods (mean ± SD)

Exercise	3-12 weeks		12-24 weeks		24-36 weeks		36-52 weeks		
	TG1	TG2	TG1	TG2	TG1	TG2	TG1	TG2	
1. Dynamic extension/flexion	Reps	MAX	37.4±3.2	MAX	44.2±5.9	MAX	60.3±7.5	MAX	68.1±10.
	Sets	2	1.9±0.1	2	1.8±0.2	3	2.3±0.3	3	2.5±0.
2. Isometric action, knee extended	Reps	5	4.9±1.2	7	7.3±0.9	7	6.4±0.4	8	6.7±1.2
	Sets	2	1.8±0.1	2	1.8±0.2	2	1.8±0.1	2	1.7±0.3
3. Isometric action, flexion 90°	Reps	6	5.6±0.5	9	7.8±0.7	9	8.8±1.1	12	9.4±1.7
	Reps	6	4.2±1.8	9	8.1±0.7	9	8.8±1.1	12	10.0±1.7
4. Isometric action, flexion 60°	Reps	6	4.2±1.8	9	8.1±0.7	9	8.8±1.1	12	10.0±1.7
	Reps	5	5.2±0.5	8	6.9±0.8	8	7.7±1.0	10	8.4±1.5
5. Isometric action, extension 90°	Reps	5	5.2±0.5	8	6.9±0.8	8	7.7±1.0	10	8.4±1.5
	Reps	5	4.9±0.8	8	7.0±0.7	8	7.7±1.0	10	8.3±1.4
6. Isometric action, extension 60°	Reps	5	4.9±0.8	8	7.0±0.7	8	7.7±1.0	10	8.3±1.4
	Reps	5	4.9±0.8	8	7.0±0.7	8	7.7±1.0	10	12.3±1.

The maximum isometric torque of the knee extensors and flexors in two different angular positions of the knee joint (60° and 90°) was measured in a sitting position (Fig. 2). The thigh was fixed on the seat in the distal part of the femur and the hips were fixed in a flexion position of 110°. The ankle was attached to the moment arm just above the malleoli. The untested leg rested on a special support and the arms were not allowed to take support during the measurements to ensure that the muscle actions were performed only by the tested leg.

The subjects performed several submaximal warm-up muscle actions before the maximum isometric torque was tested. Each maximum muscle action lasted 3-4 s. The subjects were encouraged to produce as much force as possible and as rapidly as possible during the maximum effort. Three muscle actions in each knee angle position were stored on a disk to analyze the maximum torque and the maxi-

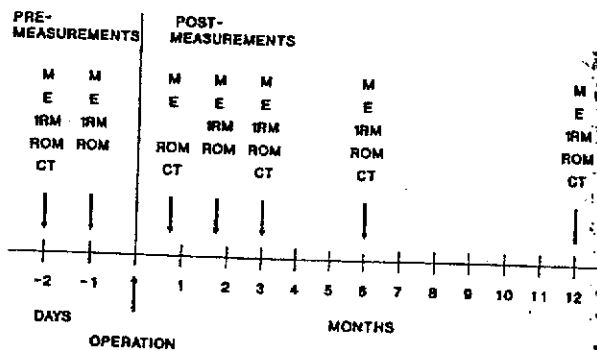


Fig. 1. The experimental design for the measurements. M = maximum isometric torque; E = EMG, 1RM = one repetition maximum; ROM = range of motion of the knee joint; CT = computerized tomography

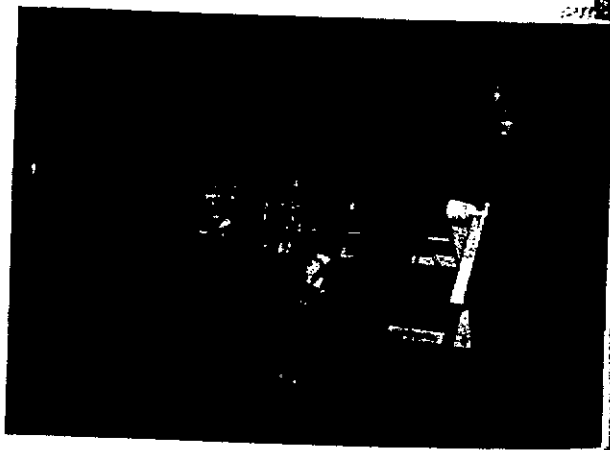


Fig. 2. The measurement apparatus and the position of the subject during maximal isometric torque measurements (EXT 60). The photo from the subject is taken 3 weeks after the operation.

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imum rate of torque development. The knee angle of 60° was used on each measurement occasion; the knee angle of 90° could not be used in the first measurement right after the operation due to the obvious risk of injury.

The variokinetic system of the testing device was used to measure 1 repetition maximum (1 RM) both in extension and flexion. In this measurement extra load was added gradually in order to record the maximum load (kg) for every subject. The testing position was the same as in the isometric muscle actions.

Bipolar technique with disposable surface electrodes (diameter 10 mm, Medicotest, Copenhagen, Denmark) was used to record electromyographic activity (EMG) from the vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), semitendinosus (ST) and biceps femoris (BF) muscles of the operated leg during the maximum isometric contractions. The electrodes were placed longitudinally on the motor point area determined by a Neuroton 626 stimulator. The EMG signals were amplified ($\times 500$) using high and low cut-off frequencies of 25 and 500 Hz. To eliminate disturbances, special preamplifier cables (Mega Electronics, Kuopio, Finland) were used. The preamplifiers were situated on the head of the cable and fixed directly on the skin with the grounding electrode. This EMG analyzing device produced root mean square (RMS) values from the electrical activity recorded. The RMS values indicate the total amount of the neural activation of the muscle in the voluntary muscle actions.

The ROM of the knee joint was measured by means of the David Rehab System in the same position as the maximum isometric torques. The subject extended and flexed the knee as much as possible and the device computed the ROM, and the maximum knee angle of extension and flexion.

The cross-sectional area (CSA) of the knee extensor group was measured and calculated by computerized tomography (CT) (Siemens Somatom DR) at the mid-point between the great trochanter and the lateral joint line of the knee. The mid-thigh was located using a tape measure. During the CT scanning the subject was in a supine position with the leg extended and relaxed. The intraobserver reliability was tested by calculating the coefficient of variance (CV) in the evaluation of the CSA. The CV between the two analyzed sessions was 1.61.

Standard statistical methods were used for the calculation of means, standard deviation (SD) and standard error (SE). The differences between the values before and after the training in all groups as well as the difference of the test and retest values of maximum isometric torque before the operation were tested by Student's *t*-test (two-tailed) for paired samples. The differences between the groups were tested

by Student's *t*-test (two-tailed) for independent samples. All statistical calculations were done using the SPSS/PC+ statistical program.

Results

Range of motion

The ROM of the knee joint decreased in both training groups ($P < 0.01$) during the first 3 weeks after the operation; the decrease in CG was not significant (Fig. 3). Thereafter the ROM recovered ($P < 0.001$) in each group and in the last measurement each group reached a slightly larger ROM compared with the preoperative ROM.

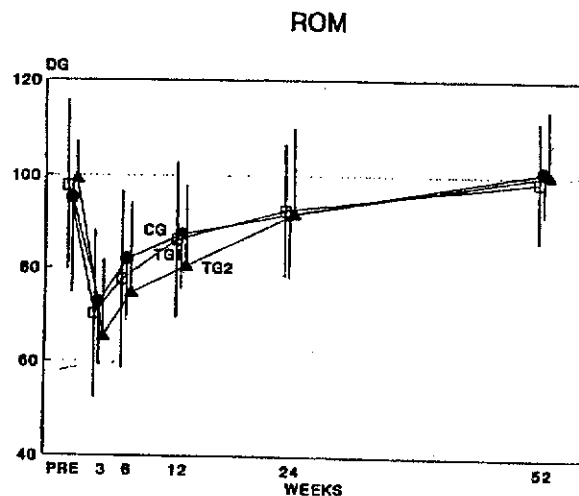


Fig. 3. Mean and SD of the range of motion (ROM) of the knee joint in TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

MAX TORQUE, EXT. 60

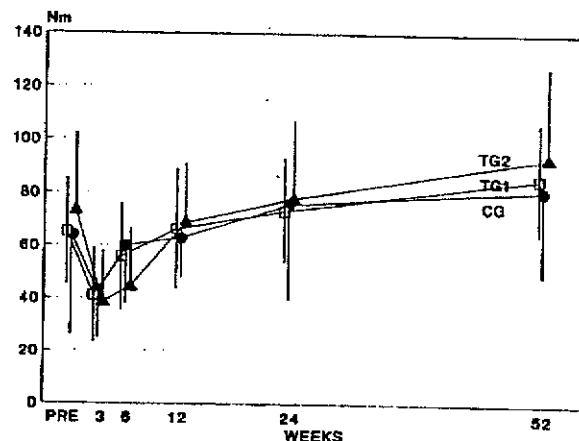


Fig. 4. Mean and SD in the maximum isometric torque in EXT 60 in TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

1 repetition maximum

After the slight initial postoperative decreases, the 1 RM in knee extension increased in each group (in TG1 $P < 0.01$ and in TG2 and CG $P < 0.05$) between the 6th and 12th weeks. Only in TG2 was the increase significant ($P < 0.05$) between the other postoperative test occasions. The relative increases of 31.2% and 12.3% in 1 RM extension during the entire period in TG1 and TG2 were greater ($P < 0.05$ between TG1 and CG) than the increase recorded in CG (2.5%). In TG1 the 1 RM knee flexion increased ($P < 0.001$) between the 6th and 24th weeks, and in TG2 the increase ($P < 0.05$) also occurred during the last training period (between the 24th and 52nd weeks). In CG the increases were also significant ($P < 0.05$) except for the change during the last training period.

Maximum isometric torque

In EXT 60 the initial decreases between the operation and the test at the third week in maximum isometric torque was significant ($P < 0.001$) in TG1 and TG2 (Fig. 4). TG1 increased its isometric maximum torque in EXT 60 during the whole training period (3rd-12th and 24th-52nd weeks, $P < 0.01$; 12th-24th weeks, $P < 0.05$). In TG2 the increase was significant between the 6th and 12th ($P < 0.01$) and between 12th and 24th ($P < 0.05$) weeks after the operation. In CG the increase was significant ($P < 0.01$) only between the 3rd and 6th weeks. The values recorded in the last test were in TG1 27.9% ($P < 0.001$), in TG2 23.2% ($P < 0.05$) and in CG 7% ($P < 0.01$) higher than the values recorded preoperatively.

After the initial decrease in EXT 90, increases

MAX TORQUE, EXT. 90

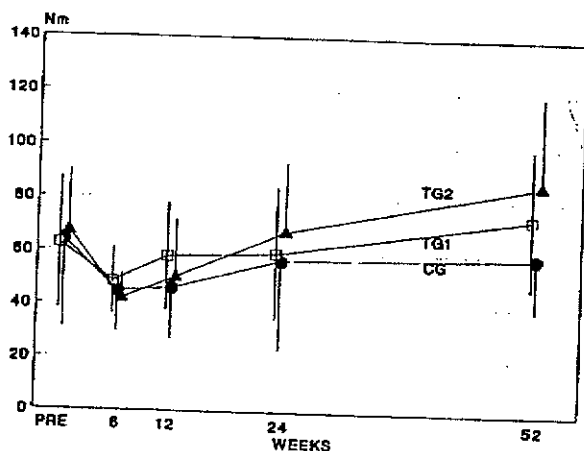


Fig. 5. Mean and SD in the maximum isometric torque in EXT 90 in TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

MAX TORQUE, FLEX. 60

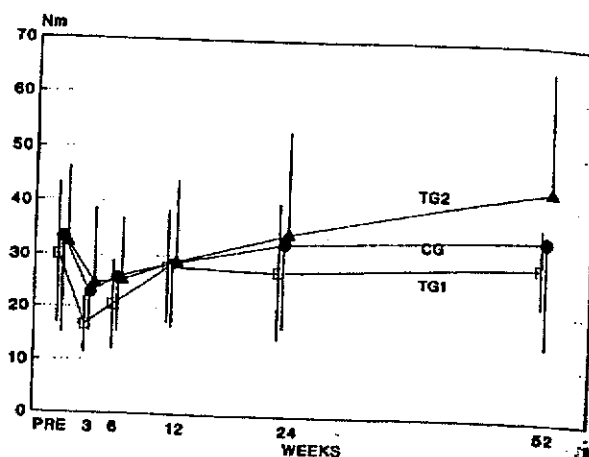


Fig. 6. Mean and SD in the maximum isometric torque in FLEX 60 in TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

($P < 0.05$) occurred in TG2 in maximum torque between the test of 6th week and all the other postoperative test occasions (Fig. 5). This increase was most dramatic ($P < 0.001$) between the 24th and 52nd weeks. TG1 and CG demonstrated no significant changes in EXT 90 during the follow-up period. Both TG1 (15.2%, NS) and TG2 (21.2%, $P < 0.05$) had also greater values in EXT 90 when the last postoperative test was compared with the preoperative one. When the groups were compared with each other, TG2 increased ($P < 0.05$) more its EXT 90 value between 6th and 12th week as compared with TG1 and CG.

In FLEX 60 the isometric maximal torque decreased both in TG1 ($P < 0.05$) and in TG2 ($P < 0.01$) during the first three weeks after the operation; the change was not significant in CG. TG1 increased its maximum isometric torque ($P < 0.01$) between the 6th and 12th weeks; in the other groups the change was not significant. However, in the last postoperative test TG1 and CG did not reach their preoperative values (-4.9% and -8.4%, respectively), whereas TG2 exceeded it (33.0%, NS) (Fig. 6).

In FLEX 90 a decrease ($P < 0.05$) occurred in maximal isometric torque during the first 6 weeks in TG1 only (Fig. 7). However, TG2 reached a slightly greater value (1.9%, NS) in the last test compared with the preoperative one, and the values for TG1 and CG were still below the preoperative levels (-30.6%, ($P < 0.01$) and -17.9% (NS) respectively).

Rate of torque development (RTD)

After the initial decreases during the first 3 postoperative weeks, RTD increased ($P < 0.05$) in EXT 60 in each group. In EXT 90 both training groups in-

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MAX TORQUE, FLEX. 90

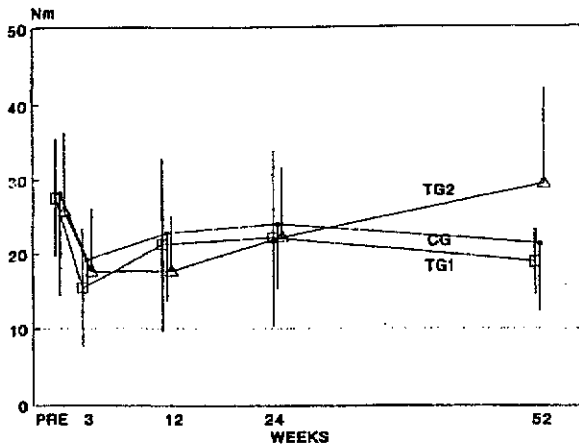


Fig. 7. Mean and SD in the maximum isometric torque in FLEX 90 in TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

RATE OF TORQUE DEVELOPMENT, EXT. 90

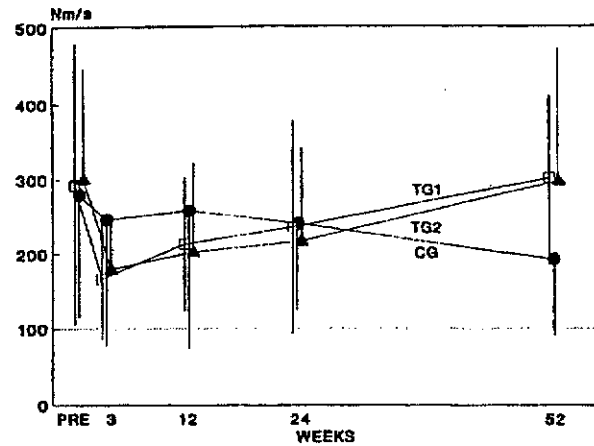


Fig. 8. Mean and SD in the rate of torque development (RTD) in EXT 90 TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

creased their RTD gradually after the test of third week, and CG showed a decrease after the 12th week (Fig. 8). TG2 increased ($P < 0.01$) RTD between the 3rd and 52nd weeks in FLEX 60. In TG1 and CG RTD increased only between the 3rd and 6th weeks. Thereafter no increases occurred in the RTD and neither group reached its preoperative values in the last test. In FLEX 90 only TG2 increased RTD after the 12th postoperative week, so that the increase was significant ($P < 0.05$) during the last follow-up period (24th-52nd weeks). The changes between TG2 and CG in EXT 90 in the RTD were significant ($P < 0.05$) between the 6th and 12th week ($P < 0.05$).

Electromyography

In EXT 60 the average EMG activity of VL, RF and VM muscles demonstrated a similar trend in all the groups during the whole postoperative period: EMG activity decreased ($P < 0.001$) during the first 3 postoperative weeks. Thereafter a gradual increase was observed (Fig. 9). In TG2 EMG activity of the RF ($P < 0.01$) and VM ($P < 0.05$) muscles increased during the entire period. After the initial decrease in TG2 during the first postoperative weeks in EXT 90, the activity of all the knee extensor muscles gradually increased (Fig. 10). The increase in the EMG activity of the RF muscle was significant ($P < 0.05$) between the 12th and 24th week in TG2. In FLEX 60 only TG2 had a significant ($P < 0.05$) increase in the EMG activity in the BF muscle between the 12th and 24th week. The increase lasted until the 52nd week. In FLEX 90 only TG2 demonstrated gradual increases in the EMG activity of the RF and VM muscles during the training period. There were no significant changes in the other examined muscles during

EMG (VL+RF+VM), EXT. 60

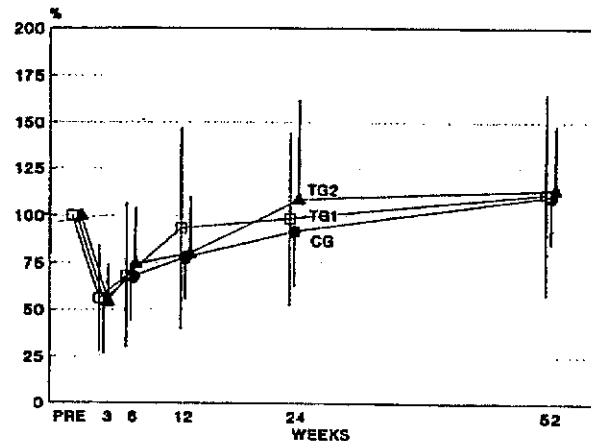


Fig. 9. EMG of the knee extensor muscles (m. vastus lateralis (VL), m. rectus femoris (RF) and m. vastus medialis (VM)) in EXT 60 in TG1, TG2 and CG during the follow-up period

the follow-up period. The individual reductions in EMG activity were related to corresponding individual changes in torque during the first 3 postoperative weeks, as presented in Fig. 11 for all subjects ($r=0.60$, $P < 0.01$).

Cross-sectional area

The CSA of the knee extensor muscle group decreased slightly in each group during the first 3 weeks, but increased slightly after that in each group (Fig. 12). From these, however, the increase was significant ($P < 0.05$) only in TG2 between the 12th and 24th week. The mean value in the CSA of TG2 during the last test was also greater ($P < 0.05$) than that

EMG (VL+RF+VM), EXT. 90

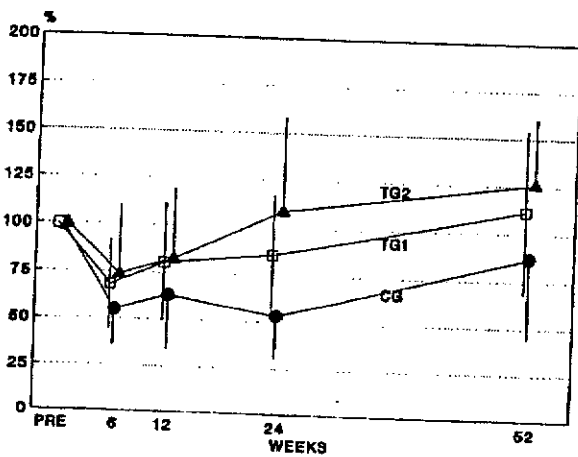


Fig. 10. EMG of the knee extensor muscles (m. vastus lateralis (VL), m. rectus femoris (RF) and m. vastus medialis (VM)) in EXT 90 in TG1, TG2 and CG during the follow-up period

of recorded preoperatively. The changes in the CSA in the other groups were in the same direction (NS).

The ratio between the maximum isometric extension torque in 60° and the CSA of the knee extensor muscle group (T/CSA) decreased during the first 3 weeks after the operation in TG1 (NS) and TG2 ($P < 0.05$) but not in CG. Thereafter each group showed increases in the T/CSA ratio during the training period, but these changes were not significant except for the change ($P < 0.05$) in TG2 between the 3rd and 12th week.

Discussion

This study showed that, after the initial decline during the first 3-6 postoperative weeks, neuromuscular function improved gradually in the elderly patients. In general, this improvement was most remarkable in TG2, which performed the greatest volume of strength training during the experimental period. It is also worth emphasizing that the initial postoperative decreases in muscle strength and in electrical activity of the knee extensor muscles were interrelated during the first postoperative weeks. These findings suggest that the level of activation is very essential to the ability of the muscle to exert force at any instant during the follow-up period. Thus, attention should be paid to the factors that may inhibit (or facilitate) muscle activation during the various phases postoperatively.

Blocking intra-capsular receptors due to the intra-articular pressure causes reflex inhibition in the quadriceps femoris muscle (27-32). This may reduce the activity of the knee extensor muscles, which in turn reduces torque production (30, 31). Indirect evidence is available to demonstrate that added intra-

TORQUE/EMG(VL+RF+VM),EXT 80, PRE-3WEEKS
TG1+TG2+CG

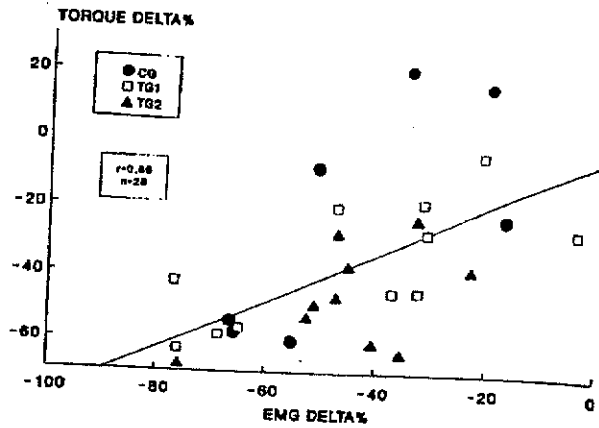


Fig. 11. The relationship between the individual changes in maximum isometric torque of the knee extensor muscles and the individual changes in EMG activity between the preoperative test and 3 weeks after the operation for all subjects

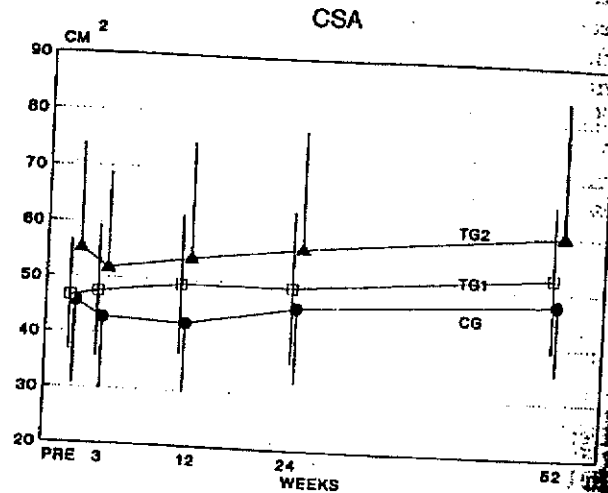


Fig. 12. Mean and SD in the cross-sectional area (CSA) of the knee extensor muscles in TG1, TG2 and CG during the follow-up period. For statistical significance, see the text.

articular pressure through effusion decreases the EMG activity of the knee extensors (28-31). Increased pressure has been thought to be indeed responsible for mechanoreceptor activation with concomitant inhibitory spinal connection to α -motoneurons (31, 32). On the other hand, if the mechanoreceptor irritation is removed by removal of the intra-articular fluid, the opposite effect will follow (32). It may be questioned, however, how these experiments, which have been performed with normal knees, could simulate the condition in the operated knees, as in the present study, where most of the receptor surfaces have been removed. However, it is likely that at least the free nerve endings in the both collateral ligaments have

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been left intact in the present operation procedures. The intra-articular swelling was present, but its influence on the reduced EMG activity cannot be explained solely by mechanoreceptor activation. Kennedy et al. (32) have indeed suggested that most swelling-induced influences are mediated through free nerve endings and pain receptors. The occurrence and magnitude of the intra-articular swelling could not be measured objectively in the present patients, whereas the extra-articular swelling could be more easily substantiated. In almost all patients this swelling lasted until the 12th week postoperatively. However, despite this extra-articular swelling, the training influence with increased EMG activity and torque values could already be seen much earlier. The extra-articular swelling should appear also around the incision site, which was on the medial side of the patella. Although the EMG analysis could not be performed reliably in each individual muscle separately, subjective observation suggested that the vastus medialis muscle was very sensitive to reduced EMG activity during the early days postoperatively.

The results seem therefore to give conclusive evidence that EMG activity is drastically reduced during the first postoperative weeks. This was associated with similar reduction in torque production. Swelling was present during this period, but it still remains to be answered what the real mechanism is that induces quadriceps inhibition where total knee joint replacement has been performed. It must be emphasized, however, that a part of the reduced EMG activity may be due to the inactivity per se, but its actual magnitude could not be substantiated in the present experiment.

During strength training the increase in maximal isometric strength is known to be accompanied by the increase in the neural activation of the trained muscles in young untrained individuals (33, 34), in untrained elderly persons (35) as well as in well trained subjects (17, 36, 37). However, intensive strength training can also cause morphological changes (hypertrophy) in the muscles, even among elderly people (10), when the period of strength training is sufficiently long. Aniansson et al. (38) have also reported that regular strength training causes hypertrophy, also in elderly women. The hypertrophy was reported to be greatest in fast-twitch fibers. Frontera et al. (10) have demonstrated similar effects of strength training resulting in the increases in the size of both fast- and slow-twitch fibers in elderly men. The maximum muscle actions used in the present training regimens may have caused sufficient training effects, also on fast-type fibers, to contribute to the increases observed in the RTD in both training groups.

The results of this study indicated, however, that, after the operation, the increase in the maximal iso-

metric torque was primarily due to neural factors. The findings are therefore in agreement with general theories of neuromuscular adaptation subsequent to strength of power training (39). Only slight changes were observed in the CSA of the knee extensor muscles of these elderly patients. Only TG2 demonstrated a significant increase in the CSA of the trained muscles during the last training periods. The volume of strength training was greatest in this particular group. The T/CSA ratio also increased gradually, which further suggests that the present training led to the improvement in the functioning of the muscle activation.

The training programs of the present groups consisted of 3 isometric knee extensor and 2 isometric knee flexor exercises, in contrast to traditional extensor exercises of the control group (CG). In EXT 60, CG demonstrated similar improvement in strength to the training groups. This may have resulted from the fact that great emphasis was put on the training with the extension exercises in CG. TG2 demonstrated considerably greater improvement in EXT90, which can result from the exercises performed in the same knee angle of 90°. The progressive increases in isometric flexor torque also demonstrate the effects of the training in TG2. The training performed in TG2, which could be recorded from the training diaries, was more voluminous and perhaps more intensive than in the other groups. Moreover, the effect of prolonged intensive strength training could clearly be observed in TG2, which increased especially the maximum isometric torque remarkably more than the other groups during the last training period (24th-52nd week). This finding indicates that intensive and progressive strength training after the total endoprosthesis operation is possible even in elderly people and, more importantly, it can also improve neuromuscular functioning.

A sufficient level of strength of the hamstring muscles is also important for the functional capacity of the knee joint. During walking, the hamstring muscles have a stabilizing and decelerating effect on the knee joint. Vegso et al. (40) have demonstrated that the hamstring muscle group loses less strength than the quadriceps group and that specific hamstring strengthening postsurgery may not be necessary. Early ambulation postoperatively stresses the hamstring muscles enough to reach the preoperative strength level. The present study demonstrated that each group reached an equal ROM of the knee joint. They also improved gradually the dynamic strength of the hamstring muscles, which also led to the increase in the ROM. However, in the maximum isometric flexor torque, TG1 and CG did not reach the preoperative values, whereas TG2 clearly exceeded it in the last test. It could be expected that increased isometric strength of the hamstring muscles could

make the knee joint more stable and the joint may be used more safely.

In summary, the results indicate clearly that muscle activation and muscle strength decreased drastically during the first weeks after the total endoprosthesis placement. The exact mechanism of this reduction is unclear, but it is very likely to be associated with increased swelling and irritation of the ligaments and extra-articular free nerve endings. However, the training program caused neuromuscular functioning to return progressively to normal. The training diaries used motivated the subjects to train regularly for their own conditioning purpose. The more voluminous and intensive training programs used in this study were more effective than the conventional one in this regard. It is therefore concluded that, when strength training is sufficiently intensive and long enough, neuromuscular performance can be improved progressively even in elderly patients who have undergone a major knee operation.

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