EFFECTS OF DETERTRAINING SUBSEQUENT TO STRENGTH TRAINING ON NEUROMUSCULAR FUNCTION IN PATIENTS WITH INFLAMMATORY ARTHRITIS

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SUMMARY

The effects of detraining subsequent to strength training on neuromuscular function were examined in 39 recent-onset rheumatoid arthritis (RA) patients. Eighteen age- and sex-matched healthy people (H) served as controls. Patients were randomly allocated either to the experimental group (PE), who carried out progressive strength training for 6 months, or to the control group (PC), who maintained only their habitual physical activities. After 6 months, PE returned to their earlier physical activities and strength training was terminated. At baseline, the maximal strength of the trunk extensors (not significant), grip strength and maximal dynamic strength and the shape of the force–time curve of the knee extensors were lower in PE and PC ($P < 0.05–0.001$) than in H. Strength training in PE led to remarkable increases ($P < 0.05–0.001$) in the maximal strength of all muscle groups without changes in the shape of the force–time curve. The increases in muscle strength in PE obtained by strength training were lost to a great degree during the detraining period for the isometric trunk extension ($P < 0.01$) and flexion ($P < 0.01$) strength and for the dynamic knee extension strength ($P < 0.05$), but not for the grip strength. In PC, trunk extension and flexion strength decreased significantly throughout the study period. At the post-test, all the strength values in both patient groups were much lower than in H. RA is a chronic disease which seems to need continuous physical exercise with sufficient intensity to minimize/prevent the loss of muscle strength and functional capacity.

KEY WORDS: Rheumatoid arthritis, Strength training, Detraining, Neuromuscular function.

One of the most unique characteristics of the musculoskeletal system is its ability to adapt to different stages of loading. The increase in muscle strength and neuromuscular function are attained only when the loading intensity sufficiently exceeds that of the normal daily activity of the individual muscles—the so-called overload principle [1–3]. At the beginning of strength training, the increase in muscular performance can be explained by neural and psychological adaptation: recruitment of more motor units per time unit, learning of more effective and economical usage of the active motor units, and reduction of the inhibitory inputs to the alpha motor neurons. After 6–8 weeks of strength training, progress is also due to gradual muscular hypertrophy [2, 4–6]. On the other hand, detraining or inactivity leads to opposite adaptive changes in the neuromuscular system depending on the decreases in the intensity and the amount of physical activity, as well as the length of the detraining period [7–10]. A certain level of muscle strength is also needed to prevent declined functional capacity and premature work loss [11, 12].

Among individuals with musculoskeletal diseases, rheumatoid arthritis (RA) accounts for a greater proportion of physician visits, restricted activity and lost work days than any other rheumatic disorder [13–16]. Thus, maintenance of the functional movement ability of joints is no doubt a primary goal of therapy for a person with arthritis. Unfortunately, patients with RA often avoid excessive movements hoping to reduce the pain or disease activity. However, inactivity and/or a decrease in physical activity produces muscle atrophy, leading to decreases in muscle strength and, consequently, in the neuromuscular performance and functional capacity [17, 18]. Our earlier study clearly indicated that the muscle strength and functional capacity of patients with arthritis are at a lower level than those of the normal population [19]. On the other hand, it has been shown that patients are able to carry out progressive strength training in order to obtain increases both in muscle mass and strength without a detrimental effect on disease activity [20–25]. An important problem is to determine when and to what extent resistance exercise training should be incorporated in the rehabilitation programme.

The aim of this study was to compare the maximal strength of selected muscle groups and the shape of the force–time curve of the knee extensors in patients with recent-onset RA with those of age- and sex-matched healthy people. Secondly, our major interest was to examine to what extent the gains of a 6 month strength training could be maintained during a prolonged 3 yr detraining period, when the initially strength-trained patients only maintained their habit-
ual physical activities. Thirdly, we re-examined the patients and healthy subjects in the control groups in order to repeat the comparison of neuromuscular function after a period of 3.5 yr.

MATERIALS AND METHODS

Subjects
Forty-three patients with recent-onset RA and 20 healthy people (H) were included in the study. The patients were randomly allocated to either the experimental group (PE) or the control group (PC). During a 3.5 yr follow-up period, one person died and another subject was lost from the PE and H groups. Thus, 21 subjects from PE (10 females, 11 males), 18 from PC (10 females, eight males) and 18 from H (nine females, nine males) completed the study. The ages and anthropometry of the subjects are shown in Table I.

Procedure
At baseline, all subjects were measured for their muscle strength characteristics. Thereafter, PE carried out progressive strength training for 6 months, while PC and H maintained their normal physical activities. The measurements were repeated at 6 months for PE and PC. Thereafter, PE also returned to their habitual physical activities including no strength training and the physical exercises performed by the subjects were no longer supervised. All patients and healthy subjects were called for renewals of the measurements on average at 42 months from the start of the study (43.0 ± 1.0 in PE, 41.8 ± 1.1 in PC and 43.1 ± 0.8 in H).

This study was a continuation of our earlier investigations. The data from the effects of progressive strength training on the neuromuscular function and disease activity in the patients with RA were presented in the first part of the study [21]. The second part of the study consisted of the comparison of the muscle strength of the patients to that of healthy persons [19]. The primary aim of this report was to examine the effects of detraining on force-production characteristics. For this purpose, it is also necessary to repeat some of the 6 month training data in this context. For the additional purpose of the present study, the same healthy controls were also remeasured in order to compare the development of neuromuscular functions between patients and healthy persons during the 3.5 yr period.

Measurements
Muscle strength. The maximal voluntary bilateral dynamic (concentric) strength of the knee extensors (one repetition maximum, 1 RM, kg) was measured by using the David 200 dynamometer [26]. The subject was in a sitting position with the hips fixed. The ankle was attached to the support just above the malleoli. After a few warm-up contractions, the load in the weight stack of the machine was gradually increased until the maximum was reached and the subject was no longer able to perform a concentric action to a full knee extension.

Maximal voluntary bilateral isometric force and force–time curves were measured using the same dynamometer. The knee angle of the measurement was at 100°. The subjects were asked to exert maximal force as rapidly as possible and to maintain that force for ~5 s. The forces were recorded on magnetic tape and thereafter digitized and analysed with a Codas TM computer system for the data measured at 0 and 6 months. In the force–time analysis, the times taken to produce the same five different force levels were calculated. In the force–time analysis at 42 months, the force levels produced at five different time periods were calculated [27] (Newtest, Oulu, Finland). The results of the isometric forces and force–time curves of the knee extensors are presented by comparing the healthy group to the two patient groups at the three different testing occasions.

Maximal isometric force of the trunk flexors and extensors was measured and analysed by a Digitest dynamometer [27, 28]. Maximal isometric grip strength was measured by a Jamar Standart dynamometer [29]. In all strength measurements, the best result was used in the final analysis.

Clinical disease parameters. Ritchie’s articular index (RI) [30], erythrocyte sedimentation rate (ESR) and haemoglobin (Hb) were used as overall indicators of disease activity.

Physical activity questionnaire. The time used for physical activity was asked by means of a questionnaire. The periods to be filled were 1 yr before the start of the study and the last year of the detraining period. The patients in both PE and PC were asked to keep training and leisure time physical activity diaries during the initial 6 month training period [31].

Training
The strength training programme has been described in detail earlier [21]. Briefly, each of the 21 patients in PE had an individually planned programme with respect to their own physical capacity. For the strength training (ST), elastic rubber bands (Thera Band®) were used for resistance and the stiffness of the band was increased according to the improvements in strength. The training programme consisted of two training sessions per week during the first 4 months and of 2–3 sessions during the last

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<td>Physical characteristics of the subjects in the experimental (PE), control (PC) and healthy (H) subjects groups at baseline (mean ± s.e.)</td>
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2 months. The programme included progressive dynamic ST for all major muscle groups of the body. Only low loads of 40% of repetition maximum (RM) were used during the first 2 months and moderate loads of 50–60% during the third and fourth months. During the last 2 months, the loads were 70–80% of RM. The patients also continued their other physical activities normally.

After the first 6 month period, the patients in PE terminated the ST for the next 3 yr and returned to their habitual physical activities. During this detraining (DT) period, the subjects were participating in leisure activities such as walking, cross-country skiing, cycling and swimming.

The patients in PC maintained their normal physical activities (similar to those in PE) after the pretests and did not participate in ST. They were also instructed to do some muscle stretching to maintain their normal range of joint motions.

The subjects in H were comparable to those participating in PC with regard to their physical activity levels. They continued their habitual activities, but were not involved in regular ST during the entire 3.5 yr period.

Statistical methods
Statistical analyses were carried out with the SPSS system. The results are expressed as the mean, range and standard error. Correlations were computed by the method of Pearson. At baseline, the differences between the three study groups were estimated utilizing analysis of variance (ANOVA). A multivariate analysis of variance (MANOVA) was then used with repeated measures. Probability-adjusted t-tests were used for pairwise comparison when appropriate. The significance level was set at \( P < 0.05 \).

Study approval
The study was conducted according to the Declaration of Helsinki and was approved by the ethics committee of the hospital.

RESULTS

Strength of the trunk muscles
At baseline, the maximal isometric trunk extension and flexion forces per body mass in both patient groups were only slightly [not significant (n.s.)] lower in comparison to the healthy persons (Figs 1 and 2). The 6 month ST in PE led to significant increases in both trunk extensor (10 ± 3%, \( P < 0.01 \)) and flexor strength (14 ± 4%, \( P < 0.01 \)), followed by decreases of 15 ± 4% (\( P < 0.01 \)) and 10 ± 5% (\( P < 0.01 \)) during the DT period, respectively. PC showed decreases of 8 ± 4% (\( P < 0.05 \)) and 8 ± 3% (\( P < 0.05 \)) in the extension and flexion strength during the whole follow-up period. H showed no changes in the strength of the trunk muscles. At the latest measurements, the respective trunk extension and flexion strengths were in both PE 15% (\( P < 0.05 \)) and 10% (n.s.) and in PC 16% (\( P < 0.05 \)) and 19% (\( P < 0.001 \)) lower than in H.

Grip strength
At baseline, both patient groups demonstrated lower isometric grip strength values per body mass in comparison to the healthy subjects (\( P < 0.001 \)) (Fig. 3). The differences between H and PE and between H and PC were 33 and 36%, respectively. During the 6 month ST period, the grip strength increased by 22 ± 6% (\( P < 0.001 \)) in PE and by 16 ± 6% (\( P < 0.05 \)) in PC, and remained elevated from the pre-treatment level throughout the additional follow-up period of 3 yr. H showed no change in grip strength during the whole experimental period. However, both PE (28%; \( P < 0.001 \)) and PC (26%; \( P < 0.001 \)) had significantly lower grip strength at the post-test compared to H.

The dynamic strength of the knee extensors
At baseline, the maximal dynamic strength of the
knee extensors per body mass (1 RM) was significantly lower \((P < 0.01)\) in PE (20%) and in PC (25%) than in H (Fig. 4). An increase of \(44\pm 9\% \) \((P < 0.001)\) took place in PE during the ST, followed by a decrease of \(9\pm 4\% \) \((P < 0.05)\) during the DT period. PC demonstrated only minor (n.s.) changes of 1 RM throughout the whole experimental period, while H showed an increase of \(20\pm 4\% \) \((P < 0.001)\) during the 42 month period. At the post-test, PE showed a 22\% \((P < 0.05)\) higher 1 RM value than PC. Respective differences of 19\% \((P < 0.01)\) between H and PE and of 37\% \((P < 0.001)\) between H and PC were measured. When RI was examined separately for the knees, only three subjects in both patient groups at month 0, one at month 6 and two at month 42 had tenderness in their knees.

The isometric force of the knee extensors

At baseline, no statistically significant differences were recorded in the isometric voluntary force of the knee extensors per body mass between the three groups (Fig. 5). PE showed no changes in this variable during the ST. At the post-test, PE had a 20\% lower isometric strength value compared to H, but the difference in the values was non-significant. In PC, the isometric force remained unaltered during the first 6 months. At the post-test, it was 32\% \((P < 0.05)\) lower compared to H.

Force–time curves of the knee extensors

The force–time curves of the knee extensors differed between the healthy subjects and patients (Fig. 6). At baseline and at 6 months, the times to produce the same force levels were longer both in PE and PC compared to H \((P < 0.05-0.01)\). No significant changes took place in the shape of the force–time curves in PE due to the 6 month ST.

At month 42, the force levels produced by both patient groups in the same short period of time remained longer \((P < 0.05)\) in both patient groups compared to H.

Disease activity

The patients were actively treated with various anti-rheumatic drugs: 81.3% in PE and 94.4% in PC of total follow-up time \((P < 0.05)\), respectively. Five cases in EG and nine in CG also used small dose of peroral corticosteroids periodically \((<10 \text{mg prednisolone/day})\). Six PE and three PC patients achieved remission, and six patients in both groups have retired prematurely due to arthritis.

The concentration of Hb remained unchanged during the whole follow-up period in both patient groups. ESR and PE decreased from 25.3\pm 5.4 to 14.0\pm 4.1 \((P < 0.05)\) and increased slightly to 18.2\pm 3.1 (n.s.) at month 42, while the alterations in PC were non-significant (from 22.1\pm 2.4 to 16.7\pm 2.7 and back to 21.1\pm 4.5). Ritchie’s articular index in PE improved from 11.2\pm 1.3 to 4.9\pm 1.1 \((P < 0.001)\) and remained the same at month 42 (5.4\pm 1.2). In PC, the corresponding changes in RI were from 13.4\pm 2.0 to 7.0\pm 1.7 \((P < 0.05)\) and 6.1\pm 1.5 at month 42.

Physical activity

The last year before the onset of the disease, PE exercised on average for 124 min and 3.3 times a week for various physical activities. During the 6 month ST period, they performed strength training...
twice a week during months 1–2 and 2.4 times during months 3–6. In addition, they had some endurance types of physical activities on average twice a week for 50–60 min at one time. After the ST period, PE returned to their habitual physical activities, exercising for 123 min averaging 3.7 times a week.

The year before the diagnosis of arthritis, the patients in the PC group exercised for 78 min, averaging 3.5 times a week. During the 6 month follow-up period the time increased to 230 min and 3.9 times a week. After the supervised period, PC returned back to about the initial durations and frequencies of their exercises. The corresponding average values in H were 113 min and 3.8 times a week the year before the pretests, and the values decreased slightly down to 76 min (n.s.) and 3.5 times during the follow-up period.

No significant differences existed between the groups in the types of leisure time activities. The most popular types of activities in all three groups were walking, biking, cross-county skiing, swimming and stretching.

**Correlation coefficients**

The initial values of grip strength per body mass correlated negatively with the corresponding increases obtained by ST in PE (r = −0.46; P < 0.05). This correlation coefficient was also significant for the 1 RM of the knee extensors (r = −0.57; P < 0.01).

The decreases in trunk extension, trunk flexion and grip strength observed during the DT period correlated negatively with the strength values recorded at month 6 in both patient groups (r = −0.45, r = −0.71 and r = −0.73; P < 0.01–0.05 in PE; and r = −0.66, r = −0.67 and r = −0.45; P < 0.01–0.05 in PC, respectively).

**DISCUSSION**

The results of earlier studies indicate that dynamic ST is not only beneficial for RA by increasing strength, but it also improves functional status, and reduces pain and fatigue [21–23]. The findings of the present longitudinal follow-up showed clearly that the ST-induced increases in muscle performance in patients with early stages of RA were lost to a great extent during the detraining period. It was also important to note that the same amount of physical leisure activities in RA patients compared to healthy subjects was not sufficient to maintain the strength level obtained by the intensive training in PE. Additionally, it was important to observe that the strength levels in PC decreased significantly during the 3.5 yr follow-up period.

The decrease in muscle strength takes place most rapidly during the first weeks of detraining/inactivity. Thereafter, it usually progresses at a diminished rate [2, 9, 10]. In this study, we recorded the amount of loss of strength, but were unable to estimate the rate of loss. However, the loss of strength was more remarkable in the subjects who were stronger before detraining. Moreover, especially in PC, the loss was more than one could expect to occur during the normal process of ageing in healthy middle-aged people. Under normal conditions, human muscle strength reaches its peak between the ages of 20 and 30 yr, and remains unchanged or decreases only slightly during the subsequent 20 yr. Thereafter, at the onset of the sixth decade, a steeper decline begins, but the loss is not necessarily the same in all muscle groups [11, 32–35]. The loss of strength we saw in this study indicates that patients should at least carry out some strength maintaining training after the intensive training season to retain the strength level reached.

The healthy subjects had significantly higher dynamic strength of the knee extensors compared to the RA patients both in the pre- and post-tests. The increase of 44% in PE due to ST was much greater than the loss of 9% during the detraining period. The correlative examination also revealed that in PE the gains by ST were most remarkable in those who demonstrated the lowest pretraining strength levels. The same phenomenon is true with healthy people, although the adaptions to ST, DT or inactivity are known to be largely individual [36]. Another important finding was the observation that at month 42 the knee extensor strength in PE remained statistically significantly elevated above the pretraining level. The healthy subjects apparently also increased their leg force during the whole follow-up period, but the reasons for the increase are difficult to explain. Nevertheless, it is important to observe that the same amount of habitual physical activities in the patients compared to healthy subjects seems not to be sufficient to maintain the normal force levels of the knee extensors in RA patients. On the other hand, some positive effects in PE could be maintained from the intensive ST period. At the post-test, the 1 RM level in PE was still higher than in PC.

At baseline, both patient groups showed lower explosive force values of the knee extensors than healthy subjects. The ST did not change the shape of the force–time curves in PE and both patient groups also differed statistically significantly from healthy subjects at the post-tests. This result obtained in RA patients supports well the concept of the effect of the specificity principle in ST reported earlier among healthy subjects [2]. The exercise programme of the patients in PE emphasized the overload principle in order to increase maximal strength. However, the movement speed used during each repetition of the exercises was probably too slow to develop explosive-type strength characteristics. It has been demonstrated earlier with RA patients that type II muscle fibres are more vulnerable to muscle disuse than the slow fibres [18]. It seems that some explosive-type ST should have been included in the training programme of the RA patients.

Maximal isometric grip strength increased significantly in both patient groups during the first 6 months and remained at the achieved level during the whole study. Simultaneously, the disease activity parameters also decreased in all patients. The parameters deteri-
orated both in PE and PC after 6 month tests, but still remained improved from the pretest values. However, the grip strength did not decrease in parallel with the ESR and RI. The proper treatment, including active anti-rheumatic medication, exercise and the normal use of the hands, seems to be of great importance for the grip strength. On the other hand, these efforts seem to be insufficient to improve the grip strength to the level of healthy persons.

At the start of the study, the isometric strength of the trunk flexors and extensors was slightly lower in both patient groups than in healthy persons. The values of PE reached the level of H during the intensive ST, but decreased again even to below the initial level after the cessation of ST. In PC, the strength of the trunk muscles decreased steadily and significantly throughout the entire experimental period. Thus, it seems that the trunk muscles did not receive enough loading during the present DT period including only the normal daily activities. This long-term decrease in strength could be explained by the functional and structural changes in the neuromuscular system, such as muscle atrophy and/or the decrease in the maximal voluntary neural activation capacity of the muscles. However, prevention of the loss of trunk muscle strength is essential for patients with RA. Poor trunk muscle function has been connected to the risk of low back disorders [37–39] and osteoporosis of the spine has been found even in the early stages of the disease [40–42].

In dynamic measurements, the increase in the strength of the knee extensor muscle group was most remarkable, while the isometric strength values of the knee extensors did not show any changes during the ST period. Since the legs are mainly used dynamically and the ST was also carried out dynamically, it was logical that the greatest changes took place in the dynamic strength of the knee extensors. The dynamic strength level could also be maintained relatively well during the DT period. On the other hand, the trunk muscles are so-called position-maintaining static muscles. In this study, the isometric tests for the trunk muscles also revealed the changes both during the ST and DT period, when the duration of the follow-up period was sufficiently long. Thus, daily use and the type of strength test of different muscle groups seem to be somewhat interrelated.

We conclude that the training programmes designed to improve muscle strength in RA patients should follow the same basic principles as for healthy people. These are the principles of overload, training progression, sufficient frequency, reversibility, specificity and individualization. However, the safety components need to be emphasized. It is also crucial to consider the phase of the disease, to measure the basic level of muscle strength and to establish proper evaluation methods for the training period. The patient should be tutored to know how to interpret the symptoms of the disease and how to adapt the programme flexibly to the changes in the disease activity. RA is a chronic and debilitating disease which seems to need continuous physical exercise of sufficient intensity to prevent the loss of muscle strength and functional capacity.

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**References**


