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Aaro Rissanen

Back Muscles and Intensive Rehabilitation of Patients with Chronic Low Back Pain

Effects on Back Muscle Structure and Function and Patient Disability

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Editors
Harri Suominen
Department of Health Sciences, University of Jyväskylä
Pekka Olsbo, Marja-Leena Tynkkynen
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ABSTRACT

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The purpose of the present study was to investigate (a) the histomorphological characteristics of lumbar paravertebral muscles in subjects without back disorders and in patients with chronic low back pain (CLBP), (b) whether exercise would induce hypertrophy in paravertebral muscle fibres in patients with CLBP, (c) the effects of an intensive rehabilitation programme, as compared with a less intensive programme, on the functioning, activities and participation of patients with CLBP and (d) the association between trunk extension endurance and long-term work disability.

The material of the muscle biopsy study in a population without history of low back disorders consisted of 21 cadavers. A total of 30 patients with CLBP volunteered for multifidus and vastus lateralis muscle biopsies. Rehabilitation programmes were compared in a controlled study of 378 CLBP patients. In a cohort study, endurance of trunk extension was measured in 535 subjects who were then followed up.

Even in subjects without any known back disorders, significant selective type 2 fibre (fast twitch) atrophy of back muscles was encountered. In CLBP patients, type 2 fibres in the multifidus had atrophied. Exercise enlarged type 2 fibres in the back muscles of men, whereas in women the size of type 2 fibres increased only in the vastus lateralis.

It can be concluded that a sedentary lifestyle does not provide adequate activation of type 2 fibres in back muscles, even in the absence of CLBP. In men, improvement in back extensor strength after the intensive exercise programme was partly ascribable to hypertrophy of type 2 fibres, whereas the strength improvement in women can only be explained by neural adaptations. Assuming that rehabilitation is partly aimed at inducing hypertrophy in atrophic type 2 fibres, women will require much longer rehabilitation programmes. While the intensive programme was particularly effective in improving body functions and activity, one year later there was no difference between the two programmes in outcome variables belonging to the component of participation of the International Classification of Functioning, Disability and Health. Based on the cohort study with an average follow-up period of 12 years, it can be concluded that good dynamic trunk extension endurance protects against back-related work disability.

Key words: low back pain, rehabilitation, muscle, histomorphology, strength, endurance, functioning, disability, ICF

Author's address	MD Aaro Rissanen Rehabilitation Unit of Helsinki City Health Care Centre BOX 6500 00099 Helsingin kaupunki, FINLAND aaro.rissanen@hel.fi
Supervisors	Docent Hannu Alaranta Käpylä Rehabilitation Centre and University of Helsinki
	Professor Esko Mälkiä Department of Health Sciences University of Jyväskylä
Reviewers	Professor Clas-Håkan Nygård Department of Health Sciences University of Tampere
	Docent Jari Arokoski Department of Surgery University of Kuopio
Opponent	Docent Timo Pohjolainen ORTON Rehabilitation Centre and University of Helsinki

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ABBREVIATIONS AND DEFINITONS

1RM	one-repetition maximum
AKSELI Programme	functional restoration programme with behavioural support
ATPase	adenosine triphosphatase
CLBP	chronic low back pain
CNT Programme	current national type rehabilitation programme
concentric strength	force exerted by a shortening muscle
EMG	electromyography
endurance	ability to maintain a specific force or power level in muscular contractions
force	an influence that changes or tends to change the state of rest or motion
ICF	International Classification of Functioning, Disability and Health
isoinertial	muscle acts against constant inertial mass
isokinetic	movement at constant angular velocity
isometric strength	force exerted by a muscle while its length remains constant
LBP	low back pain
Nm	newton metre, a unit of torque
pH	a unit related to the hydrogen ion concentration of a solution
power	the derivative of work with respect to time
SD	standard deviation
strength	maximal force exerted by a muscle at a specified velocity
torque	force multiplied by the length of the lever arm
work	force expressed through a distance

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on five original publications, which will be referred to in the text by the following Roman numerals:

I Rantanen J, Rissanen A, Kalimo H. 1994. Lumbar muscle fiber size and type distribution in normal subjects. Eur Spine J 3, 331-335.

II Rissanen A, Kalimo H, Alaranta H. 1995. Effect of intensive training on the isokinetic strength and structure of lumbar muscles in patients with chronic low back pain. Spine 20, 333-340.

III Rissanen A, Alaranta H, Sainio P, Härkönen H. 1994. Isokinetic and non-dynamometric tests in low back pain patients related to pain and disability index. Spine 19, 1963-1967.

IV Alaranta H, Rytökoski U, Rissanen A, Talo S, Rönnemaa T, Puukka P, Karppi S-L, Videman T, Kallio V, Slätis P. 1994. Intensive physical and psychosocial training program for patients with chronic low back pain. A controlled clinical trial. Spine 19, 1339-1349.

V Rissanen A, Heliövaara M, Alaranta H, Taimela S, Mälkiä E, Knekt P, Reunanen A, Aromaa A. 2002. Does good trunk extensor performance protect against back-related work disability? J Rehab Med 34, 62-66.

1 INTRODUCTION

Low back pain (LBP) is associated with a high spontaneous recovery rate, but relapses are also frequent. In LBP, it is often impossible to ascribe the pain syndrome to any particular back disease, and there is usually no specific treatment available for cases of LBP. Many of the aetiologies of LBP cannot be differentiated by clinical methods.

The incidence and prevalence of LBP increase with age up to the age of 64 years (Heliövaara 1993). In a cohort study of the Finnish population of 30 years of age or older, Heliövaara and coauthors (1989) reported medically diagnosed LBP syndrome in 17.5% of men and 16.3% of women and some disability in almost 60% of patients with LBP. In a recent report, the one-year incidence of LBP among forest workers in Finland was found to be 29% (Miranda et al. 2002). Chronic low back pain (CLBP) indicates an increased risk of reduced working capacity and occasional need for assistance among Finnish population aged 30-64 years (Mäkelä et al. 1993).

Several aetiological risk factors for LBP have been reported. Prolonged sitting, exposure to vibration or lifting tasks may increase the risk of LBP (Heliövaara et al. 1991). Lifting a box with a mass as light as 10 kg and especially lifting it from the floor leads to high load on the spine (Leskinen 1993). Sciatic pain was found to be more common among men who operate machines or do dynamic physical work than among those with sedentary jobs, but the occupational differences were considerably smaller with regard to non-specific LBP (Riihimäki et al. 1989). Mälkiä (1983) and Nygård and coauthors (1987) found that having an occupation with mainly physical demands was no guarantee of good musculoskeletal performance capacity. Poor static endurance of back muscles has been reported to predict first-time occurrence of LBP in men (Biering-Sørensen 1984). A moderate inverse linear association between leisure-time physical activity and 5-year change in LBP has been demonstrated among men in an industrial cohort (Leino 1993).

Why a self-limiting disease progresses to CLBP in some patients, has not been established. Chronic pain, psychological and social problems may affect patients with CLBP, causing impairments in body functions, activity limitations and participation restrictions. Because of the suffering of CLBP patients and social and economic considerations, there is long history of efforts to find effective rehabilitation methods to enhance functional status and activity and diminish participation restrictions in CLBP patients. The multidimensionality of the problem has prompted comprehensive rehabilitation programmes (Mayer et al. 1985a) with simultaneous application of methods of intensive physical training and behavioural support. Follow-up study (Mayer et al. 1985a) after rehabilitation has shown significant improvement in dynamometric trunk strength measurements and reduction in work-related disability among patients with CLBP.

Computerised tomography in patients with CLBP (Alaranta et al. 1993) and those undergoing spinal surgery (Mayer et al. 1989b) have revealed increased fat content in the lumbar muscles of CLBP patients, suggesting muscle atrophy. It has been reported that patients operated on for intervertebral disc herniation had selective type 2 fibre atrophy in their paraspinal muscles (Fidler et al. 1975, Ford et al. 1983, Mattila et al. 1986, Zhu et al. 1989). Rantanen and coauthors (1993) found significantly less atrophy of type 2 fibres in paraspinal muscles five years after discectomy than at the time of operation, in patients who had recovered well. No previous studies exist of the microscopic structure and its rehabilitation-induced changes in the paraspinal muscles of patients with CLBP.

1.1 The multidimensional problem of chronic low back pain

Episodes of LBP are usually very short in duration. The natural history of LBP varies in a wide range, however, with some patients becoming asymptomatic within a few days or weeks while others complain of CLBP for several years. In cases of persistent pain, efforts should be made to rule out the known specific causes of LBP (herniated disc, spondylolisthesis, neoplasm, inflammatory disease, etc.). The possibility of referred pain from other sites (intra-abdominal and pelvic diseases) should also be kept in mind in differential diagnosis of LBP.

Many structures of the back contain nociceptive nerve endings and can be the origin of LBP. These nociceptors are sensitive to mechanical irritation, such as trauma and tissue compression, and to chemical irritation (Wyke 1980, Weinstein 1986). Nociceptors have been found in the periosteum, and marrow of vertebrae, in the ligaments of the vertebral column, in intervertebral discs, in the capsules of facet joints, in blood vessel walls, in fascia, aponeuroses and other soft tissues (Wyke 1980, Konttinen et al. 1990, Kääpä et al. 1994). Pathological changes in lumbar intervertebral discs are commonly considered to be the most probable reason for LBP (Mooney 1987, Vanharanta et al. 1989). Nevertheless, magnetic resonance imaging studies often reveal similar intervertebral disc changes in subjects without any low back pain symptoms (Parkkola et al. 1993). Instead of general disc degeneration, ruptures of the outer annulus in particular have been associated with pain reproduction during discography (Moneta et al. 1994). Axonal damage in the posterior branch of the lumbar nerve root has also been presented as a reason for CLBP in patients who experience radiating or referred pain (Sihvonen et al. 1997). Furthermore, atherosclerosis of the lumbar arteries and ischaemia of vertebral tissues can cause LBP (Kauppila 1995). Sustained muscle spasm and compartment syndrome in lumbar paraspinal muscles have been reported as potential, albeit very rare causes of CLBP (Carr et al. 1985, Styf & Lysell 1987). It is obvious in the light of the above that different pathological mechanisms can cause CLBP. Kyllönen (1998) found that women with higher bone density in the spine had better isometric trunk muscle strength, which may evidence a hormonal contribution to the structure of both the vertebrae and trunk flexor and extensor muscles.

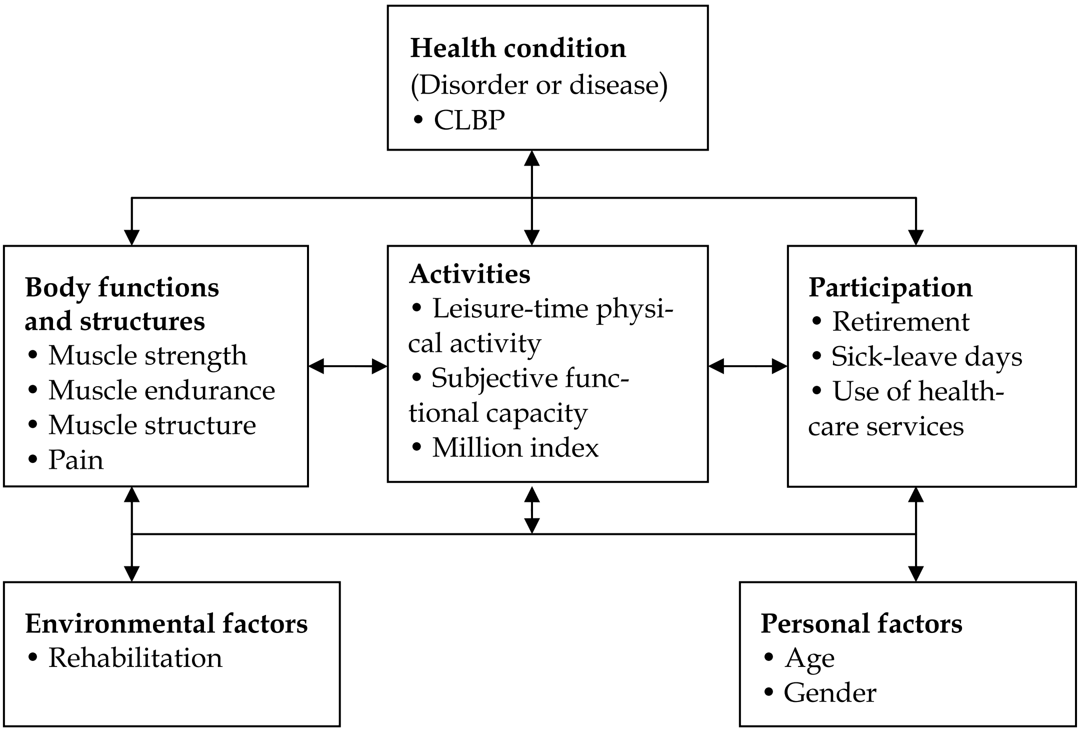


FIGURE 1 Interactions between the components of ICF and locations of the variables of the present study in the ICF framework.

The recently published International Classification of Functioning, Disability and Health (ICF) by the World Health Organization (WHO 2001) provides a unified and standard language and framework for the description of health and health-related components of well-being. The ICF has two parts, each with two components. Part 1 is Functioning and Disability with the components of (a) Body Functions and Structures and (b) Activities and Participation (Figure 1). Part 2 is Contextual Factors with the components of (c) Environmental Factors and (d) Personal Factors. ICF was not yet available when the work for the present study was done. Nevertheless, the strategy applied in the present study can be usefully described in the framework of ICF. Interactions between the various components of ICF and the locations of the variables of the present study in the ICF framework are presented in Figure 1. As shown in Figure 1, the main emphasis in the present study is in the component of Body Functions and Structures but some interactions with the Activities and Participation component are also addressed. Psychological aspects of the population of the present study have been previously reported in detail (Talo 1992, Talo et al. 1992, Rytökoski et al. 1997), and they are not dealt with in this study.

1.2 Impairments in body structure and function associated with chronic low back pain

CLBP has been suggested to lead to a deconditioning syndrome (Mayer et al. 1985a) consisting of restricted spinal flexibility, decreased trunk muscle strength and increased muscle fatigue (Nicolaisen & Jørgensen 1985, Mayer et al. 1989a). Loss of function and decrease in radiological density in back muscles have been proposed to be signs of an ongoing process in which intermittent LBP may play a role (Hultman et al. 1993). Despite some contradictory reports (Nicolaisen & Jørgensen 1985, Holmström et al. 1992), the general conclusion is that trunk extension strength in particular is markedly reduced in CLBP patients compared with healthy subjects (Nachemson & Lindh 1969, Smidt et al. 1983, Mayer et al. 1985b, Burdorf et al. 1992). Several authors have also reported poor back muscle endurance in patients with CLBP (Nicolaisen & Jørgensen 1985, Mayer et al. 1989a). According to Kankaanpää and coauthors (1998), the gluteus maximus muscle fatigued more rapidly during an isometric back extension test in CLBP patients than in healthy controls. Here, inadequate fitness of back muscles may be a causal factor. An association between poor back muscle endurance and LBP has been reported by several authors (Biering-Sørensen 1984, Leino et al. 1987, Luoto et al. 1995). In addition, Hemborg and Moritz (1985) observed that CLBP patients had weaker abdominal muscles, compared with healthy subjects. In spite of this deficiency in abdominal muscle strength in CLBP patients, these authors found no difference between CLBP patients and healthy subjects in intra-abdominal pressure during lifting.

Whether the reduced trunk muscle strength and endurance in CLBP patients is caused by impaired motor unit recruitment due to decreased central drive, or perhaps by structural deficits in trunk muscles, is unknown. Several reasons may be put forward for poor trunk muscle strength and endurance in CLBP, such as pain, pain avoidance behaviour, prolonged physical inactivity and lack of motivation in the test situation. Could lack of physical activity cause actual structural changes in lumbar muscles? Measuring trunk muscle cross sectional areas by magnetic resonance imaging, Parkkola and coauthors (1993) found that the psoas, erector spinae and multifidus muscles of CLBP patients were smaller and contained more fat deposits than did the muscles of control subjects. It appears, however, that better information on the contractile characteristics of trunk muscles could be achieved by microscopic analysis. Atrophy of type 2 (fast twitch) fibres has been encountered in multifidus muscles of discectomy patients (Fidler et al. 1975, Ford et al. 1983, Mattila et al. 1986, Zhu et al. 1989). On the other hand, Mattila and coauthors (1986) reported similar findings in some control subjects as well. There is a need for studies of back muscle structure in both sexes and in a wide enough age range.

Co-ordination of trunk motion was lost during fatiguing dynamic sagittal loading (Parnianpour et al. 1988). The fatigue of trunk muscles after dynamic loading also disturbs the ability to sense lumbar position and its changes (Taimela et al. 1999). Luoto and coauthors (1998) obtained poorer results in postural sway and one-footed balance tests in CLBP patients than in controls. Poor muscle endurance and loss of co-ordination may predispose the spine to cumulative microtrauma and subsequent CLBP and disability.

1.3 Activity limitations and participation restrictions associated with chronic low back pain

Activity is the execution of a task or action by an individual (WHO 2001). Owing to pain and negative changes in body structure and function, the quality and quantity of occupational and leisure-time activity may be reduced in CLBP. Limitations of activity may already be evident after three months of pain (Waddell 1993) and may affect 75% of patients with CLBP (Heliövaara et al. 1989). The degree of activity limitation depends not only on the characteristics of the individual but also on many environmental factors. Activity limitations in CLBP patients can be documented by questionnaires concerning back-related tasks or movements in ordinary daily activities. The most frequently used measures of LBP and its consequences are the Million index (Million et al. 1981, 1982) and the Oswestry index (Fairbank et al. 1980).

Participation is involvement in a life situation by an individual (WHO 2001). CLBP, impaired body structures and functions and limited activity can also lead to restricted functioning at the social level. The most important changes in the participation of CLBP patients occur in occupational life. Effects such as reduced work ability, work absenteeism and disability retirement are determined not only by personal factors but also by environmental factors such as culture, work issues, employment, financial policies and national social security systems (Frymoyer 1992, Waddell 1993, Wickström et al. 1993, Kuorinka et al. 1995, Grönblad et al. 1996).

1.4 Rehabilitation of patients with chronic low back pain

In acute non-specific LBP, anti-inflammatory analgesics will diminish pain and improve back function from the third day of treatment (Pohjolainen et al. 2000). Deyo and coauthors (1986) concluded that it was not useful to rest longer than two days in acute LBP. Patients with acute LBP do not benefit from therapeutic back exercises (Faas et al. 1993, Malmivaara et al. 1995). Pain killers and the maintenance of the ordinary daily activities is an adequate treatment regimen for these patients. In CLBP, possible changes in patients' body structures and functions, activity levels or participation render the problem multidimensional and difficult to solve. The high economic costs and the suffering of patients as a result of CLBP have prompted strategies to avoid low back injury (McGill 1997) and methods to rehabilitate patients. Hazard and coauthors (1991) divided rehabilitation methods into three categories: pain management, work hardening and functional restoration programmes.

The inhouse functional restoration programme modelled by Mayer and coauthors (1985a) has been an example for several other programmes later on. In multidisciplinary programmes the impairments in body structure and function, activity limitations and participation restrictions are treated with a combination of physical exercises, psychological and social or occupational interventions. The setting in these programmes can be inhouse or outpatient. The duration and intensity of different treatment modes also vary. Even though the improvement in body function of CLBP patients is remarkable after functional restoration programmes, the evidence concerning vocational outcomes is still controversial (Guzmán et al. 2001).

Physical exercises administered by a physiotherapist have been used to manage CLBP. In this context, exercise may be defined as series of specific movements for the purpose of training the body through systematic practice to promote physical health (Nordin & Campello 1999). Usually therapeutic exercise programmes are a combination of several specific exercise techniques for spinal flexibility, co-ordination, cardiovascular fitness, muscle strength and muscle endurance (Linton et al. 1989, Bendix et al. 1995). Kuukkanen & Mälkiä (1996) found that a progressive physical exercise programme and an individual home exercise programme both reduced LBP, improved back-specific function and increased muscle strength over nine months in subjects with CLBP. Hansen and coauthors (1993) concluded that CLBP patients in moderate or heavy manual occupations tended to respond better to conventional physiotherapy, whereas intensive back exercises would be most effective for those with physically undemanding jobs. Nevertheless, there is also evidence (van Tulder 2000b) suggesting that exercise therapy may be superior to conventional pharmacological care in improving daily activities and helping return to work in patients with CLBP. Muscle strength training is an important element of most rehabilitation programmes for CLBP patients, but the long-term protection afforded by good trunk muscle performance against work disability has not been investigated in population studies. In spite of many controlled clinical trials, there is still no clear-cut research evidence of the effects of exercise dose, exercise duration and different exercise modes on the outcome of rehabilitation of patients with CLBP.

Several kinds of back and abdominal muscle exercises have been recommended for stabilisation of the spine. Arokoski and coauthors (2001) showed that muscle activation during stabilisation exercises was much higher in women than in men. In other studies, stabilising exercises have been suggested to produce insufficient trunk muscle recruitment for a muscle-strengthening effect (Souza et al. 2001, Hubley-Kozey & Vezina 2002). In a study by Niemistö and coauthors (2003), brief manipulative treatment in combination with stabilising exercises and a physician consultation proved to reduce pain and disability better than a physician consultation alone. Spinal manipulation has been used alone to treat CLBP. In a meta-analysis, manipulative therapy was not shown to be better than other advocated therapies, such as analgesics, exercises, physical therapy or back schools (Assendelft et al. 2003).

Back-school methods have been developed to rehabilitate patients suffering from subacute or chronic LBP (Hall 1980, Kennedy 1980, Mattmiller 1980, Zachrisson-Forssel 1980). Back-school programmes consist of physical training and ergonomic education or training and education in the basics of anatomy, physiology, pathology of spine and self-treatment. Some programmes also address the psychological aspects of LBP. A literature review (van Tulder 2000a) suggests that back-school programmes carried out at workplaces may be effective for recurrent LBP or CLBP.

Behavioural treatment administered by a pain management team appears to diminish pain and improve functioning in patients with CLBP, compared with untreated patients (van Tulder et al. 2001). On the other hand, behavioural treatment alone does not seem to add to the effectiveness of ordinary drug therapy in relieving pain and improving functioning. Further research is needed to identify those CLBP patients who will benefit from behavioural treatment and to determine the most effective mode of therapy.

1.5 Lumbar paraspinal muscles

1.5.1 Anatomy and function

The macroscopic anatomy and segmental innervation of human lumbar back muscles is described in detail elsewhere (Bogduk 1980, Macintosh et al. 1986, Macintosh & Bogduk 1986, Macintosh & Bogduk 1987, Kalimo et al.1989). Lumbar back muscles comprise three groups: (a) interspinales and intertransversarii mediales, which are short intersegmental muscles; (b) thoracic components of both longissimus thoracis and iliocostalis lumborum, which are long polysegmental muscles and only cross the lumbar region in their distal attachments mainly to the bony pelvis; (c) paraspinal muscles, which are polysegmental muscles and attach to the lumbar vertebrae. The paraspinal muscles in the lumbar region consist of the multifidus and the lumbar segments of the longissimus thoracis and iliocostalis lumborum. The multifidus muscle is the most medial of the paraspinal muscles, and it runs in the groove formed by the spinous processes and laminae of the vertebrae (Figure 2). The longissimus and iliocostalis muscles are situated lateral to the multifidus (Figure 3).

The lumbar multifidus muscle consists of five separate fascicles. Each of these bands has a separate origin on a spinous process of LI-LV and attaches to a particular transverse process of vertebrae LIII-LV, to the posterior iliac crest or to the lateral part of the sacrum (Figure 2). The lumbar segment of the longissimus thoracis consists of five fascicles which originate at the accessory processes and adjacent transverse process of lumbar vertebrae and attach caudally to the iliac crest (Figure 3). Fascicles that arise from the more cranial lumbar vertebrae run more dorsolaterally. The fascicles arising from vertebrae LI—LIV have long caudal tendons that form the lumbar intermuscular aponeurosis between the longissimus and iliocostalis muscles. The lumbar segment of the iliocostalis comprises four fascicles, each arising from the tip of a particular transverse process of vertebrae LI—LIV and attaching to the dorsal iliac crest. Without prominent caudal tendons, these fascicles have fleshy insertions to the dorsal iliac crest.

Lumbar muscles extend, flex laterally and rotate the lumbar spine and provide stability for it (Macintosh & Bogduk 1986, Kalimo et al. 1989). Lumbar muscles also participate in co-ordination of lumbar flexion. The contribution of bones and ligaments to the stability of the lumbar spine is rather low (Crisco et al. 1992), and the lumbar spine is unstable in the absence of muscular activity. The main action of multifidus muscles is to produce posterior sagittal rotation of the lumbar vertebrae and stabilise the lumbar spine. Experiments have shown the multifidus muscles to be an important stabiliser of the lumbar spine (Wilke et al. 1995). Extension is produced by bilateral contraction of the iliocostalis lumborum and longissimus thoracis. Unilateral contraction of the iliocostalis lumborum and longissimus thoracis produces lateral flexion. Axial rotation is mainly caused by unilateral contraction of the iliocostalis lumborum, with slight contributions by the lumbar segments of the longissimus and multifidus.

1.5.2 Histomorphology

The generally accepted histochemical classification divides muscle fibres into two main types, 1 and 2, with type 2 fibres being further divided into subtypes 2A, 2B and 2C (Dubowitz 1985). The two main fibre types can be differentiated using standard ATPase (adenosine triphosphatase) staining (with preincubation at pH 9.6 or 10.4), producing intensive staining of type 2 fibres and weak staining of type 1 fibres. The subtypes of type 2 fibres can be identified on the basis of their selective reaction in standard ATPase staining after preincubation at pH 4.6 or 4.3.

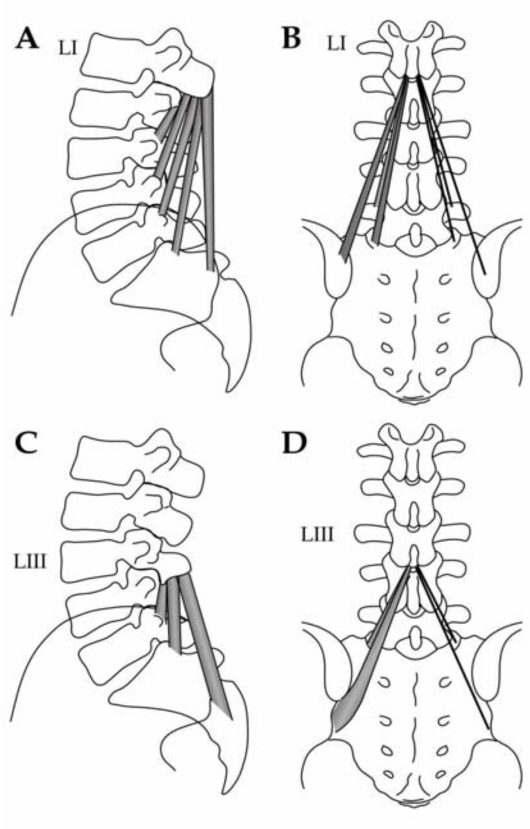


FIGURE 2 Schematic illustration of the multifidus muscle at the levels of vertebrae LI (A—B) and LIII (C—D). The fascicles of the lumbar multifidus originate at the spinous processes of vertebrae LI-LV and attach in a multisegmental manner to the transverse processes of vertebrae LIII—LV, to the posterior iliac crest and to the sacrum. (Reproduced from Macintosh et al. 1986.)

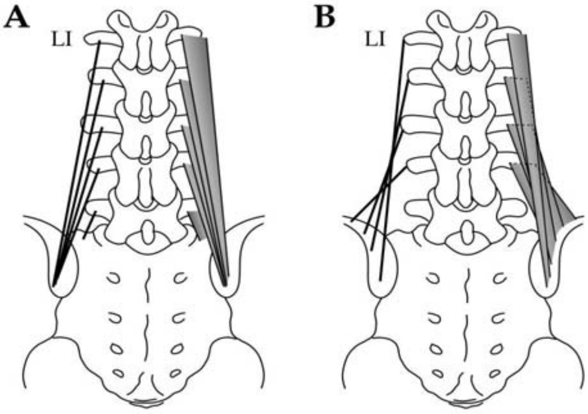


FIGURE 3 Schematic illustration of the lumbar segments of longissimus thoracis and iliocostalis lumborum. The fascicles of the longissimus (A) originate at the accessory processes and adjacent transverse processes and attach to the iliac crest. The fascicles of the iliocostalis lumborum (B) each originate at the tip of a particular transverse process, and they attach to the iliac crest. (Reproduced from Macintosh & Bogduk 1987.)

The two main types of muscle fibre also differ in physiological properties. Type 1 fibres twitch slowly but their high content of oxidative enzymes makes them extremely resistant to fatigue. Whereas all type 2 fibres are fast twitching, the subtypes differ in their amounts of glycolytic and oxidative enzymes. Type 2A fibres are to some extent resistant to fatigue while type 2B fibres are fatigue sensitive. Type 2C may represent a fibre capable of differentiation into type 2A or 2B (Dubowitz 1985). During muscle contraction, type 1 fibres are first recruited. If stronger muscle contraction is needed, all type 1 fibres are recruited, and type 2 fibres are recruited in increasing numbers. Type 1 fibres are used in performances that last long and require low muscle tension. Type 2 fibres are recruited in fast muscle contractions and in performances characterised by high muscle tension. Fibre distribution denotes the proportions of type 1 and type 2 fibres in a sample of muscle tissue. Fibre distribution varies in a wide range among individuals and also between different muscle groups.

1.5.3 Mutability

Muscle force and contraction speed is produced in an interactive process involving the central nervous system, motor neuron pools and the internal and external mechanics of muscles (Komi 1979). Muscle strength may improve as a result of regular exercise or heavy work. Short-term high-load training undertaken by untrained subjects increases muscle strength quickly owing to neural adaptations. In the first weeks of training the subjects improve the coordination necessary to perform the exercise efficiently (Sale 1992). Other neural adaptations, such as the ability to recruit motor units at very high rates, may require a longer period of training and will be lost rapidly during detraining (Sale 1992). With continued training further increase in strength is also accounted for by hypertrophic influences (Häkkinen 1985). Fibre hypertrophy involves a process by which a myofibril undergoes longitudinal splitting into two or several myofibrils (Goldspink 1992). In a comparative study of muscle fibres in the vastus lateralis muscles of untrained individuals, weightlifters and endurance athletes, Edström & Ekblom (1972) found that the size of type 1 fibres was unrelated to maximal isometric muscle strength as well as aerobic capacity. Endurance athletes had type 2 fibres equal in size to those of untrained individuals, whereas weightlifters had significantly larger type 2 fibres than the other two groups. According to MacDougall and coauthors (1980) and Häkkinen and coauthors (1981), heavy-resistance strength training induces hypertrophy in both type 1 and type 2 fibres in leg muscles. Staron and coauthors (1989) demonstrated that strength training with weights can induce significant hypertrophy in type 1 and type 2 fibres in vastus lateralis muscles even in women .

Although varying widely among people of the same age, age-related muscle atrophy and strength loss in the vastus lateralis muscle are considered to be the result of changes in neural activation and a greater reduction in contractile material of type 2 fibres than type 1 fibres, the latter effect being due to a reduction in the number and/or size of type 2 fibres (Larsson 1982, Lexell et al. 1983, Häkkinen & Häkkinen 1991, Lexell & Downham 1992). Still, heavy-resistance strength training can also improve muscle strength in elderly men and women through adaptations of the nervous system as well as through muscle fibre hypertrophy (Häkkinen & Häkkinen 1995). Selective atrophy of type 2 fibres often occurs in association with muscle pathology. Disuse or inactivity of a muscle group secondary to other causes may also lead to atrophy of both type 1 and type 2 fibres (MacDougall et al.1980, Häkkinen et al. 1981, Rose and Rothstein 1982). In discectomy patients, good recovery has been associated with improvement in type 2 fibre size in back muscles (Rantanen et al. 1993). It is not known whether similar reversible changes in muscle fibres could be induced by sufficiently intensive physical rehabilitation in patients with CLBP.

1.6 Measurements of trunk performance in patients with chronic low back pain

1.6.1 Strength measurements

Isometric measurement is the oldest dynamometric method assessing trunk strength. It measures maximal strength at a selected position of trunk flexion or extension. Hasue and coauthors (1980) suggested that the isometric method allowed appropriate trunk strength measurements in CLBP patients who were afraid of increased pain during trunk movements.

Technological advantage made it possible to measure the maximal concentric muscle strength throughout the range of motion of the extremities at a preset constant angular velocity (Hislop & Perrine 1967). A similar isokinetic dynamometric method also became popular in the measurement of trunk strength in CLBP patients (Smidt et al. 1983, Smith et al. 1985). Isokinetic devices can measure torque, work and power at preset angular velocities and some devices are able to measure both concentric and eccentric strength. Isokinetic trunk extension strength, in particular, has been shown to be lower in CLBP patients (Mayer et al. 1985b). Nevertheless, the clinical value of isokinetic dynamometric strength measurements in CLBP patients, as compared with less expensive and more easily available tests, warrants separate study.

1.6.2 Endurance measurements

The static back endurance test measures isometric endurance of trunk extensors (Biering-Sørensen 1984). In the test, the subject is asked to hold his/her unsupported trunk horizontal as long as possible. Low static back endurance predicted first-time occurrence of LBP in men (Biering-Sørensen 1984).

The dynamic endurance of trunk flexion of CLBP patients has been measured with the repetitive sit-up test and that of trunk extension by repetitive arch-up test (Alaranta et al. 1990). In these tests, hip flexor or extensor muscles also contribute to trunk movements (Farfan 1995). CLBP patients achieved poorer results in arch-up and sit-up tests, compared with healthy subjects (Alaranta et al. 1994).

In the isoinertial dynamometric method, constant resistance is provided in the three cardinal planes of motion, and the velocity of trunk motion is under voluntary control of the individual tested. The method monitors torque, angular velocity and trunk position (Parnianpour et al. 1990).

Myoelectric changes in localised muscle fatigue have been intensively studied (Moritani et al. 1986), and surface electromyography (EMG) has become an important means of measuring trunk extensor fatigue (Mayer et al. 1989a).

2 PURPOSE OF THE STUDY

The present study was conducted to provide answers to the following research problems:

1. What are the histomorphological characteristics of various lumbar muscles and various sites in the multifidus muscle in people without back disorders?

2. What are the histomorphological characteristics of the multifidus and vastus lateralis muscles in patients with CLBP?

3. What are the effects of an intensive rehabilitation programme on the strength and morphology of back and leg muscles in patients with CLBP?

4. What is the value of isokinetic trunk muscle strength measurement in comparison with conventional nondynamometric tests in the evaluation of back function in patients with CLBP?

5. What are the effects of an intensive physical and psychosocial training programme, as compared with a less intensive conventional programme, on the functioning, activities and participation of patients with CLBP?

6. What is the association between dynamic back extension endurance and long-term back-related work disability?

3 SUBJECTS AND STUDY DESIGN

The overall design of the present study and the subjects in the five substudies (Studies I—V) are presented in a flow chart in Figure 4. The study was approved by the Ethical Review Committee of the Invalid Foundation.

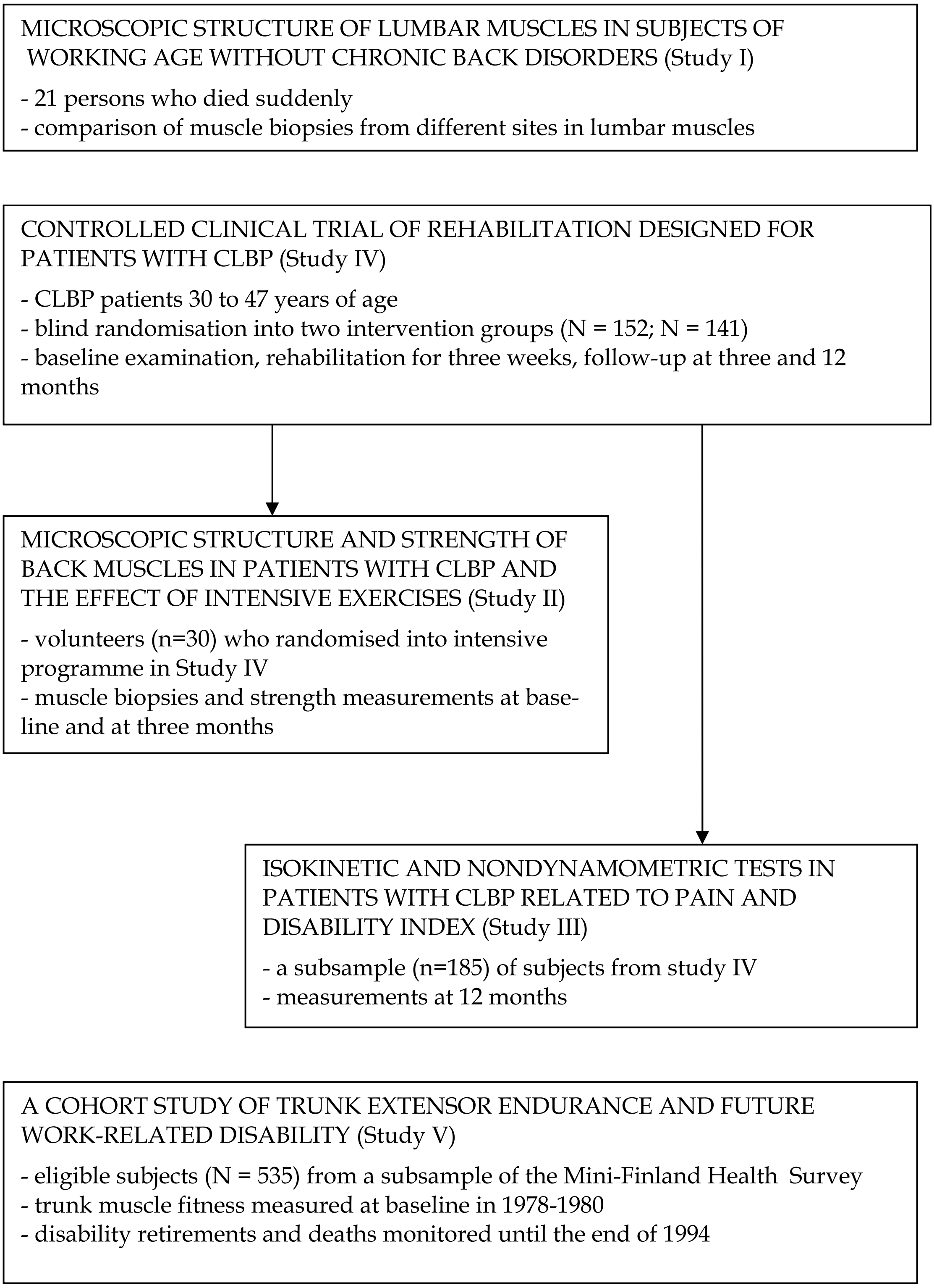
3.1 Subjects and design (Study I)

The study material comprised 21 cadavers (14 male, 7 female) in the age range of 23—65 years (mean 44.7 years) without evidence of low back problems in hospital or health-care centre records. Histometric variables on samples taken from various sites in lumbar paraspinal muscles were measured, and the effects of biopsy site, age and sex on the results were analysed.

3.2 Subjects and design (Study II)

The study population consisted of 30 volunteers (14 men, 16 women) participating in intensive rehabilitation for CLBP patients (AKSELI Programme; see 3.4 Subjects and design; Study IV). The age range of men and women was 31—47 years (mean 39.9 years) and 34—47 years (mean 40.8 years), respectively. The subjects' LBP symptoms had lasted three years on average. None of the subjects had clinically evident symptoms of lumbar nerve root compression at baseline. EMG revealed only borderline denervation activity, maximally one fibrillation per muscle in 10 subjects. Four of these patients exhibited borderline denervation activity in paraspinal muscles, three in leg muscles and three in both paravertebral and leg muscles. Biopsies were taken from the lumbar multifidus and vastus lateralis muscles at baseline and three months later. Isokinetic trunk extension and knee extension peak torque were also measured. One woman was unable to perform the trunk extension test at the angular velocity of 120°/s.

One woman did not participate in the follow-up examination at three months. Two women refused leg muscle biopsies at three months but did allow back muscle biopsies to be taken.



MICROSCOPIC STRUCTURE OF LUMBAR MUSCLES IN SUBJECTS OF WORKING AGE WITHOUT CHRONIC BACK DISORDERS (Study I)

- 21 persons who died suddenly
- comparison of muscle biopsies from different sites in lumbar muscles

CONTROLLED CLINICAL TRIAL OF REHABILITATION DESIGNED FOR PATIENTS WITH CLBP (Study IV)

- CLBP patients 30 to 47 years of age
- blind randomisation into two intervention groups (N = 152; N = 141)
- baseline examination, rehabilitation for three weeks, follow-up at three and 12 months

MICROSCOPIC STRUCTURE AND STRENGTH OF BACK MUSCLES IN PATIENTS WITH CLBP AND THE EFFECT OF INTENSIVE EXERCISES (Study II)

- volunteers (n=30) who randomised into intensive programme in Study IV
- muscle biopsies and strength measurements at baseline and at three months

ISOKINETIC AND NONDYNAMOMETRIC TESTS IN PATIENTS WITH CLBP RELATED TO PAIN AND DISABILITY INDEX (Study III)

- a subsample (n=185) of subjects from study IV
- measurements at 12 months

A COHORT STUDY OF TRUNK EXTENSOR ENDURANCE AND FUTURE WORK-RELATED DISABILITY (Study V)

- eligible subjects (N = 535) from a subsample of the Mini-Finland Health Survey
- trunk muscle fitness measured at baseline in 1978-1980
- disability retirements and deaths monitored until the end of 1994

FIGURE 4 The subjects and study design.

3.3 Subjects and design (Study III)

A total of 185 CLBP patients (96 men and 89 women, a subgroup from Study IV) participating in 12-month follow-up examinations at the Invalid Foundation performed isokinetic trunk strength tests and conventional nondynamometric repetitive tests. The age range of the subjects was 30 to 47 years (mean 40.5 years). The mean duration of back pain was six years in men and four years in women. Seven men and 14 women had previous surgeries for lumbar intervertebral disc herniation. The mean Million index (Million et al. 1981, 1982) was 30 in men and 38 in women. Associations between the trunk muscle performance tests and the Million index were analysed.

3.4 Subjects and design (Study IV)

The basic study population consisted of CLBP patients in the age range of 30 to 47 years for whom the Social Insurance Institution had decided to finance an inhouse rehabilitation period. The main inclusion criteria were back disease without inflammation and back pain of at least six months' duration. The subjects had not received or applied for disability pension. The formation of the study population and the design of the study are presented in detail in Figure 5. A total of 378 subjects were stratified according to age (≤40 years and >40 years) and sex and randomised into intervention and control groups. At the baseline examination, 85 subjects were excluded blindly with respect to randomisation mainly because of contraindications for intensive physical training.

Three weeks after baseline both groups started an inhouse rehabilitation programme lasting three weeks. The AKSELI Programme of the intervention group (AKSELI group) was carried out at the Rehabilitation Research Centre of the Social Insurance Institution and at the Invalid Foundation. The current national type programme (CNT Programme) of the control group (CNT group) was arranged at five rehabilitation centres. Follow-up examinations took place three and 12 months after the baseline examination.

3.5 Subjects and design (Study V)

This cohort study investigated dynamic trunk extensor performance (arch-up) as a predictor of work-related permanent work disability. The study was performed on subjects from a random subsample of the comprehensive Mini-Finland Health Survey (Aromaa et al. 1989) carried out between 1978 and 1980. The study population of the Mini-Finland Health Survey consisted of a two-stage cluster sample drawn from the population register and stratified to represent adult Finns of 30 years of age or older. The formation of the present study population (267 men and 268 women, 54% of the subsample) from the random subsample is presented in Figure 6. After baseline measurements, the mortality of the cohort and new disability pensions granted to the participants were monitored until the end of year 1994.

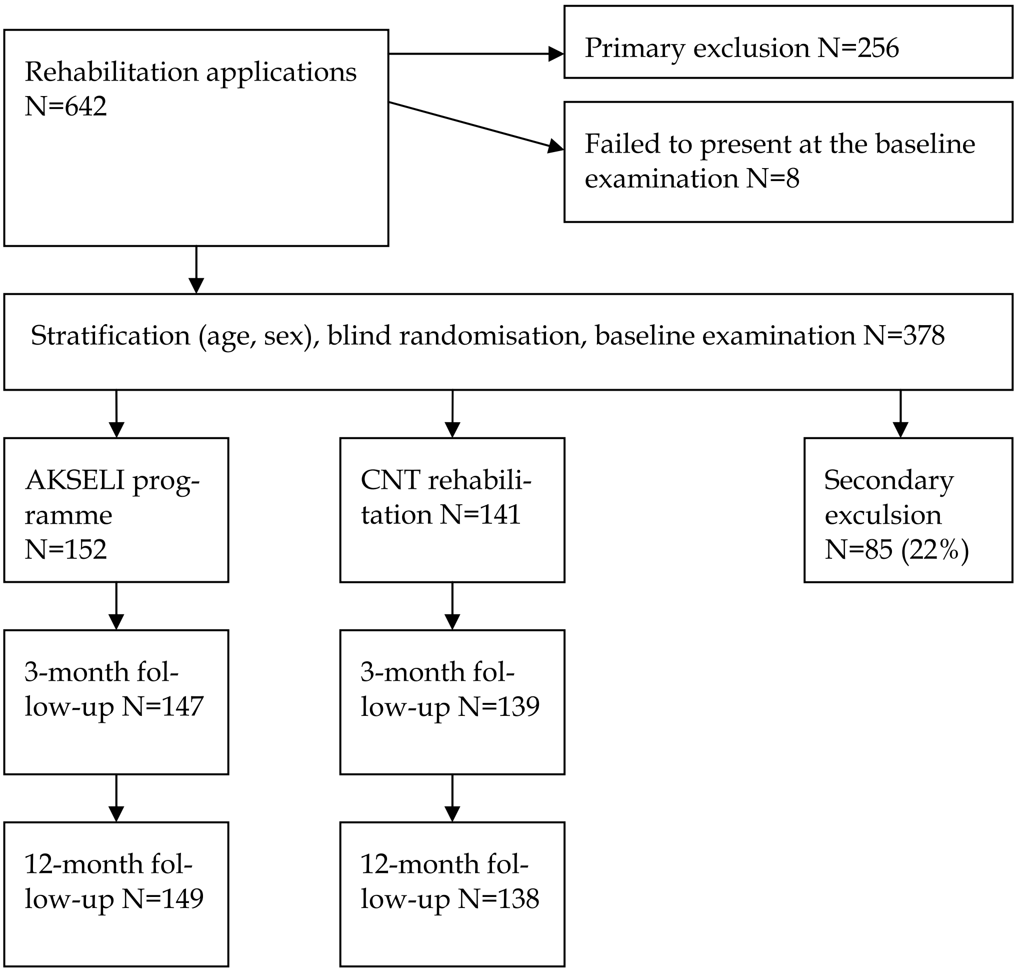


FIGURE 5 Formation of the study population and the design of Study IV.

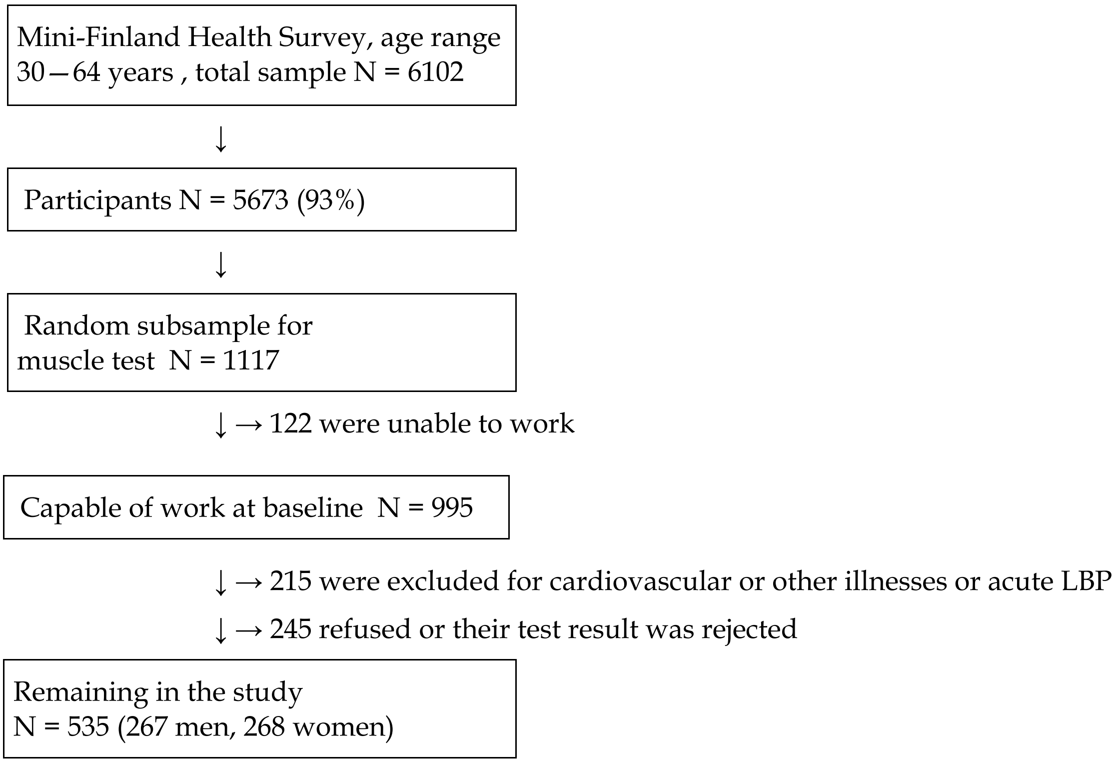


FIGURE 6 Formation of the study population of Study V.

4 METHODS

4.1 Measurements of muscle structure and function

4.1.1 Measurements of histomorphology (Studies I and II)

The microscopic structure of lumbar paraspinal muscles in healthy subjects (Study I) was investigated by obtaining tissue samples of about 1 cm^3 each from different sites in the multifidus and iliocostalis lumborum muscles of cadavers. The samples were excised directly through an incision made in the skin and fascia. The ventromedial corner of the lumbar paraspinal muscle group, i.e. the deep multifidus muscle at intervertebral level LIV—LV, was sampled in all 21 cadavers (Figure 7). Additional samples were taken from cadavers no. 10 to 21 from the superficial part of multifidus (Mfs in Figure 7B) and the deep and superficial parts of iliocostalis lumborum (ILd and ILs in Figure 7B) at intervertebral level LIV—LV . Samples were also taken from deep multifidus muscle at levels LIII—LIV and LV—SI from these 12 cadavers (Figure 7A).

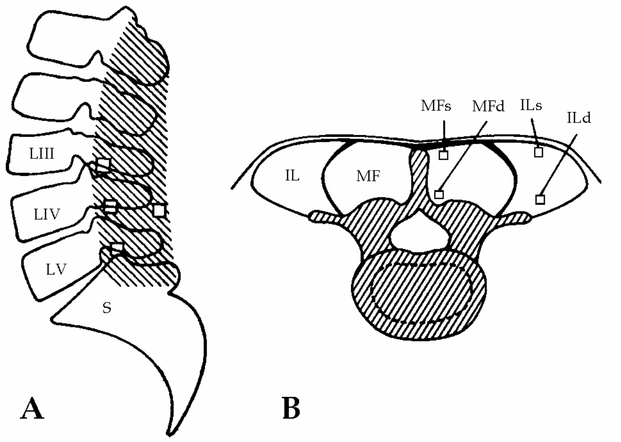


FIGURE 7 Schematic illustration of biopsy sites in lumbar muscles in sagittal plane (A) and horizontal plane (B). Biopsy sites: MFd, deep multifidus; MFs, superficial multifidus; ILd, deep iliocostalis lumborum; ILs, superficial iliocostalis lumborum.

The semi-open muscle biopsy technique (Henriksson 1979) was used to sample the multifidus and vastus lateralis muscles of 31 CLBP patients who volunteered for Study II. Before the semi-open biopsies were undertaken, the correct biopsy site in the deep multifidus muscle at intervertebral level LIV—LV was demonstrated in one subject by placing an injection needle at the presumed site and verifying its correct location by computerised tomography. The vastus lateralis muscle was sampled using the same technique at the border between the distal and middle thirds of the thigh. Follow-up biopsies were taken after three months 1 cm cranially from the baseline biopsy site to avoid any artefact caused by the previous biopsy. The muscle samples were immediately frozen and stored in a freezer at -70°C until histomorphological measurements.

In Study I, transverse sections of muscle samples were stained using haematoxylin and eosin, van Gieson and ATPase staining. In ATPase staining, acid (pH 4.3) and alkaline (pH 10.4) preincubations allowed the identification of muscle fibres of different types (Dubowitz 1985). The morphometric analysis was done by two persons and comprised measurements of the total areas of sections, the numbers of fibres and the cross-sectional areas and lesser diameters of individual fibres (Song et al. 1963, Dubowitz 1985), using a digitising table connected to a microcomputer programmed for morphometric analysis. An average of 286 (range 177—390) muscle fibres per biopsy were measured.

In Study II, transverse sections of muscle tissue were stained with ATPase with preincubation at pH 10.4 to differentiate fibre types 1 and 2. The numbers of type 1 and type 2 fibres were counted and their lesser diameters measured by two persons using a microcomputer. The mean number of fibres analysed for each patient were 235 (SD 33) and 218 (SD 39) at baseline and 225 (SD 33) and 225 (SD 57) at follow-up in the multifidus and vastus lateralis muscles respectively. The muscle sample areas were randomly selected for analysis in both Studies I and II. The outline of the selected area was drawn on paper. Afterwards a third person, an experienced pathologist, used the drawings of the sections to verify the consistency of the morphological measurements by the two other persons. The pathologist verification was maintained throughout Studies I and II.

4.1.2 Measurements of isokinetic strength (Studies II and III)

Concentric isokinetic trunk and knee strength was measured with an Ariel 4000 isokinetic dynamometer (Ariel Dynamic Inc., Trabuco Canyon, CA, USA). Before the first actual test at baseline, the subjects practised with the isokinetic device to accustom themselves to it and the test procedure. In the isokinetic strength test, the subjects performed three maximal efforts at 10-s intervals at each angular velocity. There was a 30-s interval between different velocities. The highest peak torque obtained was recorded for data analysis. In Study II, maximal peak torque of trunk extension and flexion at angular velocities of 30°/s and 120°/s was used as the strength parameter, and it was not related to total body weight. In Study III, additionally average torque, work, peak power and average power were measured at angular velocities of 30°/s, 120°/s and

150°/s, and the parameters were related to total body weight. Maximal peak torque of knee extension (Study II) was measured at angular velocities of 30°/s and 180°/ without using the option provided by the device for correction for body weight.

All isokinetic measurements and device calibrations were done by two trained physiotherapists in a standardised manner. The calibration of the device was verified before each measurement session and the device was recalibrated as required. In the isokinetic measurements, the variation in average torque tested using two different weights was kept with ±2.3%. The consistency of isokinetic trunk flexion-extension measurements with this device and the subject stabilisation system were previously examined with 20 healthy volunteers (unpublished data: Sainio 1994). Pearson's correlation coefficient (r) for intratester values ranged from 0.85 to 0.95. The intertester r values ranged from 0.82 to 0.94 for torques and from 0.54 to 0.96 for work and power. Bland-Altman plots showing the consistency of isokinetic trunk extension strength measurement in the present study are presented in the results. The validity and reproducibility of Ariel 4000 isokinetic dynamometer results for unilateral knee strength have been reported elsewhere (Jacobs & Pope 1986).

In isokinetic tests, the starting point and the range of trunk and knee movements were standardised and stored by the device for each subject for follow-up measurements. A computer simulation has shown the axis of movement of the lumbar spine to be at the vertebral body of LIII (Stokes 1987). In the present study, isokinetic trunk flexion-extension was measured with the subject standing and the axis of movement aligned with the most cranial part of the iliac crest (closer to the vertebral body of LII than LIII), as the iliac crest is a bony landmark easily located by palpation. Momentary back pain during the isokinetic trunk flexion-extension test procedure was quantified using the visual analogue scale (score range 0—10).

4.1.3 Measurements of endurance (Studies III, IV and V)

In repetitive arc-up, sit-up and squat tests, the movement was repeated until the performance no longer fulfilled the preset criteria. The performance rate was one repetition per 2-3 s. In the squat test, men wore sleeves weighing 10 kg and women wore sleeves weighing 7 kg. The subjects were allowed to rest their hands on a bench to help maintain balance during the squat test. In the static back endurance test, the result was the number of seconds the subject was able to maintain the acceptable test position. The consistency of the repetitive tests has been reported previously, with r ranging from 0.63 to 0.87 for intratester values in a series of 93 subjects and from 0.66 to 0.95 for intertester values in a series of 34 subjects (Alaranta et al. 1994). The consistencies of the tests supervised by different physiotherapists were monitored during the study.

In Study V, arc-up and sit-up tests were used to measure trunk extension and flexion endurance. The arch-up test was done with the trunk in a forward leaning position (Figure 8). The legs and thighs of the person were fastened to the test bench at 50° from horizontal, with the hands held behind the neck. The test movement started from the flexed position (upper trunk at horizontal level), and the trunk was extended repetitively to a position of 50º. The range of the test movement was standardised. The repetitions was done as fast as possible. The test result was the number of repetitions in 30 s. A test-to-test analysis of the method previously yielded an r value of 0.83 between two measurement sessions at a 12-month interval (Mälkiä 1983).

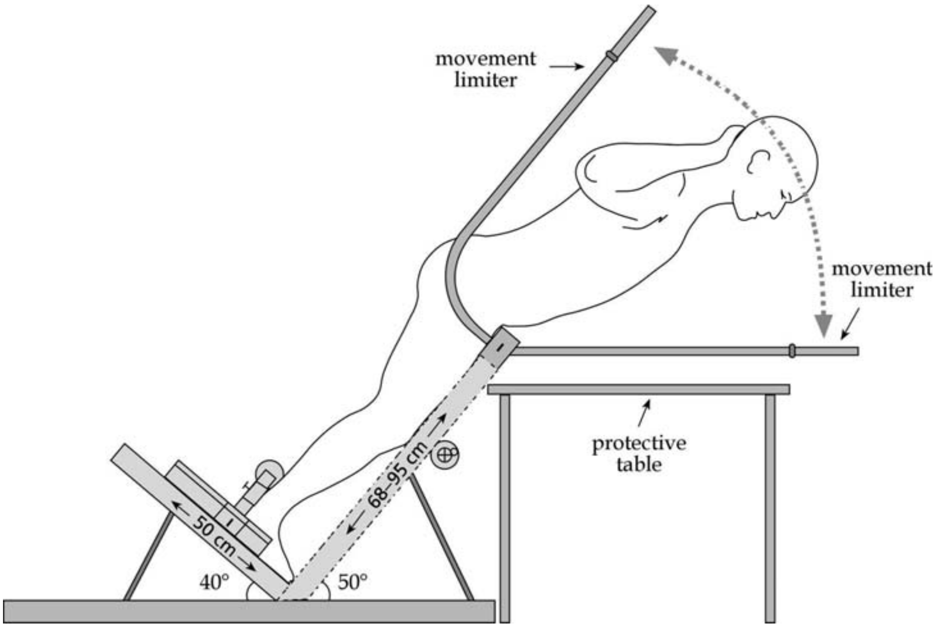


FIGURE 8 Test bench designed for the standardised arch-up test in Study V. (Reproduced from Mälkiä 1983.)

In the sit-up test, the subject lay on his/her back with knees bent at 90º, feet fastened to the test bench and hands held behind the neck. The movement started with the head and shoulders touching the bench and ended with the elbows touching the knees. The test result was the number of repetitions in 30 s. The value of r between two measurement sessions at a 12-month interval was 0.92 (Mälkiä 1983).

4.2 Measurements of activity

4.2.1 Million index (Studies II, III and IV)

The pain and disability index presented by Million and coauthors measures pain and perceived back-specific functions in the daily activities of patients with LBP (Million et al. 1981, 1982). The Million index was chosen as a measure of patient activity for the present study, as it had been found to be acceptably consistent in previous rehabilitation studies (Mayer et al. 1985a, Hazard et al.

1989). Alaranta and coauthors (1990) reported that its test-retest r in 20 patients with LBP was 0.88. The subjects in the present study estimated the severity of their pain and disability on a continuous line of 100 mm (Appendix 1). The mean of patient estimates in response to 14 questions was used as an index of pain and disability. The range of the scale was 0—100 (0 = no pain or disability; 100 = the worst possible pain or disability).

4.2.2 Subjective physical performance at work and leisure-time physical activities (Study IV)

At the baseline and follow-up examinations, the subjects graded their subjective low back performance at work according to the following categories: (1) no occurrence of back problems or occurrence only in heavy physical activities, (2) occurrence of back problems in moderate physical activities, (3) occurrence of back problems in light physical activities or at rest. Leisure-time physical activity was estimated using questions about the intensity, duration and frequency of physical exercises, fitness training and other physical activities. An index was formed on the basis of these items (Appendix 2). In contrast to Million index both of these scores are lacking previous reports of consistency and validity.

4.3 Measurements of participation

4.3.1 Use of health-care services (Study IV)

The number of visits to doctors because of LBP and the number of courses of outpatient physical therapy during the preceding 12 months were recorded at baseline and at 12 months.

4.3.2 Sick-leave days (Study IV)

The number of sick-leave days because of LBP during the preceding 12 months was obtained from the local offices of the Social Insurance Institution at baseline and at 12 months.

4.3.3 Retirements (Studies IV and V)

Data on new disability pensions granted to the subjects were obtained from the pension register of the Social Insurance Institution. The primary diagnosis appearing on the medical certificate used in granting a permanent disability pension was recorded as the cause of work-related disability in the present study. In Study IV, new disability retirements were monitored for 12 months after baseline. In Study V, new disability retirements were monitored from 1978 to 1994 (the mean follow-up period was 12 years, corresponding to 6559 person-years).

4.4 Rehabilitation programmes

Two inhouse rehabilitation programmes were compared. The physically more intensive rehabilitation programme with cognitive-behavioural disability management (AKSELI Programme) resembled the functional restoration programme described by Hazard and coauthors (1991). The details of the exercise methods in the AKSELI Programme are presented in Appendix 3. The programme was carried out at two institutes: the Rehabilitation Research Centre of the Social Insurance Institution and the Invalid Foundation. The CNT Programme was in common use in Finland at the end of the 1980s.

It was carried out at five rehabilitation centres. The amount and intensity of exercise performed by each patient were documented at the end of the three-week rehabilitation programme. Cognitive-behavioural disability management groups were not included in the CNT Programme. Compared with the AKSELI Programme, the physical strenuousness of the CNT Programme was approximately 40—50% (15-20 h of physical exercise per week). Both programmes were initiated three weeks after the baseline examination and lasted three weeks.

4.5 Statistical analyses

The statistical analyses were performed using SAS (SAS User's Guide 1985a, 1985b), BMDP (Dixon 1988) and SYSTAT (SYSTAT 1987) software. The distributions of categorical variables were compared between groups with the chi-square test or, in the case of small frequencies, with Fisher's exact test. Group comparisons of approximately normally distributed numeric variables were made with the t test, and nonnormally distributed numeric variables were analysed using the Wilcoxon test. Within-group changes in numeric variables were studied with the paired t test (normal distribution) or paired Wilcoxon test (nonnormal variables). The significances of changes in categorical variables were tested by categorical linear modelling using the CATMOD procedure in SAS. In Study V, adjusted means and multiple partial correlation coefficients were estimated using the general linear model (Searle 1971). Cox's life-table regression model (Cox 1972) was used to estimate the association between dynamic trunk extension performance and the incidence of work-related disability. Both confounding and effect-modifying factors were entered into the model. Adjusted relative risks with 95% confidence intervals and likelihood ratio tests (expressed as exact P values) were based on this model.

5 RESULTS

5.1 Muscle structure and function

5.1.1 Microscopic structure of paraspinal muscles in subjects without chronic low back pain (Study I)

The mean frequencies of type 1 and type 2 muscle fibres in the deep multifidus in all cadaver subjects ($N = 21$) were 63% and 37%, respectively. The fibre distribution varied only slightly among different sites in the paraspinal muscle group: superficial and deep multifidus, superficial and deep iliocostalis lumborum (Tables 1 and 2). There were no statistically significant differences between sexes, or between subjects above and below the age of 45 years. On average, 57% of the total cross-sectional area of all biopsies at intervertebral level LIV—LV consisted of type 1 fibres, 17% of type 2 fibres and 26% of nonmuscular tissue (mainly fat and connective tissue). In men, the area of type 2 fibres was on average 19.5%, compared with 10.9% in women ($P < 0.05$). There were no significant differences between sexes or age groups in the amount of nonmuscular tissue.

Type 1 fibres were significantly ($P < 0.001$) larger than type 2 fibres at all sampling sites in paraspinal muscles (Tables 1 and 2). The mean lesser diameter of type 1 fibres in the deep multifidus at intervertebral level LIV—LV (the reference point for Study II) was 55.1 µm in men and 51.6 µm in women, a nonsignificant difference. The lesser diameter of type 2 fibres at the same site differed significantly ($P < 0.001$) between the sexes, being on average 38.8 µm in men and 28.4 µm in women. Age had no significant influence on fibre diameter, nor did biopsy site within the muscle group (Table 2).

TABLE 1 Fibre distribution and lesser diameter of type 1 and 2 fibres in deep multifidus muscle at intervertebral level LIV—LV.

	Fibre type	Fibre distribution (%)	Lesser diameter (μm)
All subjects (N = 21)	type 1	62.6	54.0 (9.2) ∗†
	type 2	37.4	35.4 (8.8)
Men (N = 14)	type 1	61.5	55.1 (10.3) †
	type 2	38.5	38.8 (8.9) ‡
Women (N = 7)	type 1	68.5	51.6 (6.7) †
	type 2	31.5	28.4 (2.3)

∗ mean ± SD
† Type 1 vs. 2 fibres, P < 0.001
‡ Men vs. women, P < 0.001

TABLE 2 Fibre distribution and lesser diameter of type 1 and 2 fibres in different levels (LIII-SI) of lumbar muscles.

	MFd LIV—LV (N = 21)	MFs LIV—LV (N = 12)	ILd LIV—LV (N = 12)
Type 1 (%)	62.6	57.4	66.6
Type 1 diameter (μm)	54.0 (9.2) ∗	57.1 (10.8)	55.9 (10.2)
Type 2 diameter (μm)	35.4 (8.8)	33.8 (7.0)	35.2 (9.2)

	ILs LIV—LV (N = 12)	MFd LIII—LIV (N = 12)	MFd LV—SI (N = 12)
Type 1 (%)	66.5	69.6	61.7
Type 1 diameter (μm)	57.1 (15.2)	52.9 (7.2)	57.8 (10.2)
Type 2 diameter (μm)	35.3 (10.7)	33.9 (12.1)	34.5 (7.8)

MFd, deep multifidus; MFs, superficial multifidus; ILd, deep iliocostalis lumborum; ILs, superficial iliocostalis lumborum
∗ mean ± SD
All differences between biopsy sites are statistically nonsignificant.

5.1.2 Microscopic structure of back and leg muscles in patients with chronic low back pain and changes induced by an intensive rehabilitation programme (Study II)

The distribution and size of muscle fibres at baseline and at three months are presented in Table 3 (multifidus) and Table 4 (vastus lateralis). At baseline, the mean percentage of type 1 fibres in all multifidus and vastus lateralis samples was 67 and 48, respectively, a statistically significant difference ($P < 0.001$). The changes at three months in fibre distribution of the multifidus or vastus lateralis were statistically nonsignificant. In the multifidus, type 2 fibres were significantly ($P < 0.001$) smaller than type 1 fibres. In the vastus lateralis, type 2 fibres were smaller than type 1 fibres at baseline but the difference was less marked ($P < 0.01$) than in the multifidus. The intensive rehabilitation appeared to reduce the difference in size between type 1 and type 2 fibres. No statistically significant increase in the lesser diameter of type 1 fibres of the multifidus (1% in men, 3% in women) or vastus lateralis muscles (1% in men, -2% in women) was found after the intensive rehabilitation programme. Conversely, the mean lesser diameter of type 2 fibres increased in men by 11% ($P < 0.05$) and 8%

TABLE 3 Proportion of type 1 fibres in the multifidus muscles of patients with CLBP at baseline and at three months, and three-month change in the mean lesser diameter of muscle fibres.

	Men (N = 14)	Women (N = 16)	Total (N = 30)
Proportion of type 1 fibres			
Baseline (%)	68 (13)*	65 (12)	67 (12)
Three months (%)	68 (14)	69 (9)	69 (12)
Type 1 lesser diameter			
Baseline (µm)	72 (8)‡	69 (11)‡	71 (10)‡
Three months (µm)	73 (10)‡	71 (10 ‡	72 (10)‡
Change (%)	1	3	1
Type 2 lesser diameter			
Baseline (µm)	45 (9)	38 (8)	41 (9)
Three months (µm)	50 (8)†	42 (10)	46 (10)†
Change (%)	11	11	12

* mean ± SD
† statistically significant difference between baseline and three-month values, $P < 0.05$
‡ statistically significant difference between type 1 and 2 fibres in the multifidus muscle, $P < 0.01$

($P < 0.05$) in the multifidus and vastus lateralis muscles, respectively. In women, the corresponding increases were 11% ($P < 0.16$, statistically nonsignificant) in the multifidus and 11% ($P < 0.05$) in the vastus lateralis.

TABLE 4 Proportion of type 1 fibres in the vastus lateralis muscles of patients with CLBP at baseline and at three months, and three-month change in the mean lesser diameter of muscle fibres.

	Men (N = 14)	Women (N = 14)	Total (N = 28)
Proportion of type 1 fibres			
Baseline (%)	47 (13)*	49 (12)	48 (12)
Three months (%)	45 (12)	44 (9)	44 (10)
Type 1 lesser diameter			
Baseline (μm)	74 (9)‡	64 (7)‡	69 (10)‡
Three months (μm)	75 (14)	63 (10)	69 (14)
Change (%)	1	-2	0
Type 2 lesser diameter			
Baseline (μm)	64 (7)	53 (7)	59 (9)
Three months (μm)	69 (10)†	59 (6)†	64 (10)†
Change (%)	8	11	8

* mean ± SD
† statistically significant difference between baseline and three-month values, $P < 0.05$
‡ statistically significant difference between type 1 and 2 fibres in the vastus lateralis muscle, $P < 0.01$

5.1.3 Changes in isokinetic trunk and knee extension strength induced by an intensive rehabilitation programme (Study II)

The isokinetic peak torques of trunk extension at baseline and at three months are presented in Table 5 and the peak torques of knee extension in Table 6. The peak torque of isokinetic trunk extension at angular velocities of 30°/s and 120°/s increased 14% and 16%, respectively, in men and 33%, and 23%, respectively, in women. The peak torque of knee extension at angular velocities of 30°/s and 180°/s increased 7% and 5%, respectively, in men and 18% and 9%, respectively, in women. All the increases in peak torque of trunk and knee extension were statistically significant ($P < 0.05$). Weight-adjusted peak torque did not provide more information compared with absolute peak torque when the strength change was analysed.

The intensity of momentary LBP during the isokinetic strength test procedure did not correlate with trunk extension peak torques at baseline or at three months. There was no statistical association between the three-month change in pain score during the strength test and with the change in peak torque.

TABLE 5 Maximal peak torques (Nm) of isokinetic trunk extension measured at angular velocities of 30°/s and 120°/s at baseline and at three months and the three-month change (%).

	Men (N = 14)	Women (N = 16)	Total (N = 30)
30°/s			
Baseline	179.4 (31.8) *	111.9 (29.3)	144.5 (45.6)
Three months	205.0 (39.1)	148.3 (27.1)	175.7 (43.7)
Change (%)	14	33	22
120°/s			
Baseline	146.8 (32.1)	86.2 (25.0)†	115.5 (41.7)†
Three months	171.0 (41.6)	106.3 (22.8)†	137.5 (46.3)†
Change (%)	16	23	19

* mean ± SD
† women, N = 15; total, N = 29
All three-month changes are statistically significant ($P < 0.05$).

TABLE 6 Maximal peak torques (Nm) of isokinetic knee extension measured at angular velocities of 30°/s and 180°/s at baseline and at three months and the three-month change (%).

	Men (N = 14)	Women (N = 14)	Total (N = 28)
30°/s			
Baseline	188.5 (36.7) ∗	115.0 (31.5)	151.7 (50.3)
Three months	201.4 (33.0)	135.8 (27.8)	168.6 (44.9)
Change (%)	7	18	11
180°/s			
Baseline	113.7 (14.1)	70.9 (14.8)	92.3 (26.0)
Three months	119.9 (15.1)	77.2 (16.0)	98.6 (26.5)
Change (%)	5	9	7

∗ mean ± SD
All three-month changes are statistically significant ($P < 0.05$).

5.1.4 Changes in repetitive and static back tests at three and twelve months (Study IV)

Repetitive sit-up (Figure 9) and arch-up (Figure 10) improved significantly more in the AKSELI group compared with the CNT group in both men and women over three months. At 12 months, these differences still persisted in men with regard to both tests but in women only with regard to the repetitive sit-up test. In the squat test, men and women in the AKSELI group improved their performance over three months more than those in the CNT group (Table 7). In static back tests (Table 7), there were no differences between the groups, but women in both groups showed improved performance at both three months and 12 months.

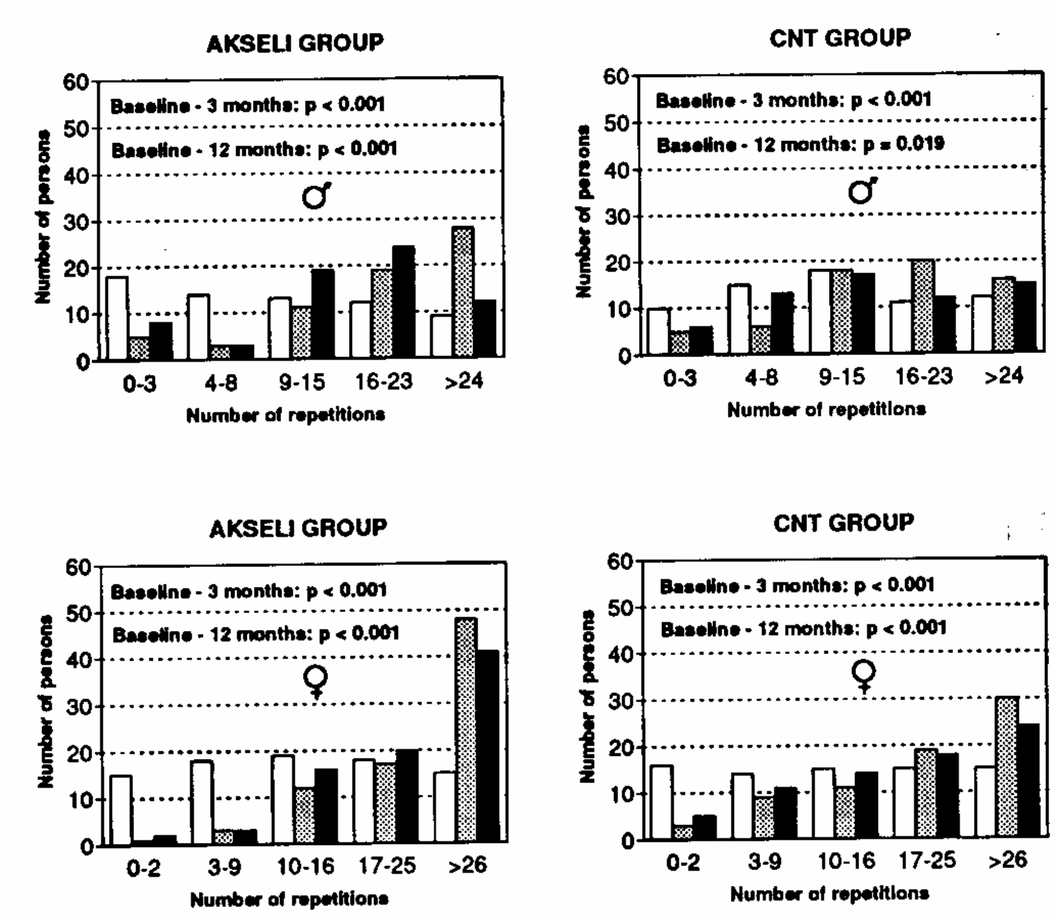


FIGURE 9 Repetitive sit-up test at baseline, 3 month, and 12 month follow-up in Study IV. Open bars = baseline, hatched bars = three months, closed bars = 12 months. The changes from baseline to three months and 12 months were statistically (categorical linear model; SAS/CATMOD) significantly greater in the AKSELI group than in the CNT group in both men ($P = 0.002$ and $P = 0.025$, respectively) and women ($P = 0.024$ and $P = 0.031$, respectively). P values in the figures, Wilcoxon signed rank test.

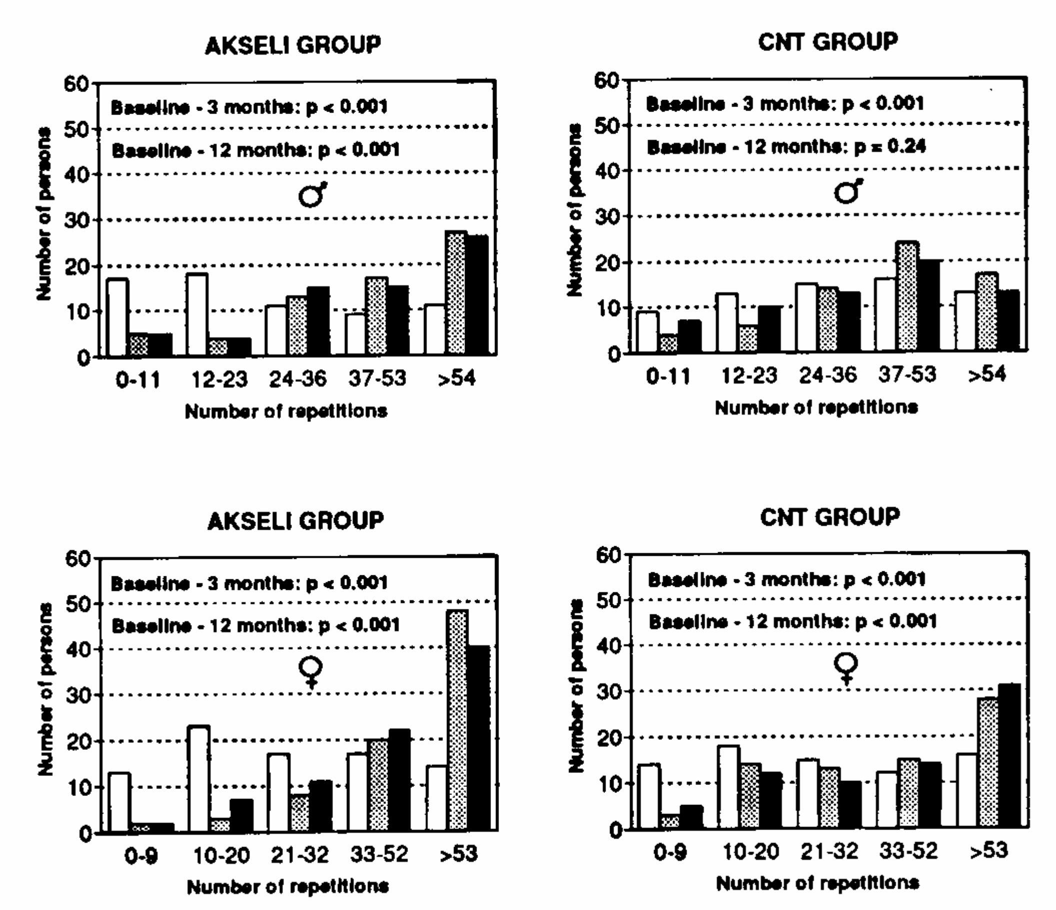


FIGURE 10 Repetitive arch-up test at baseline, 3 month, and 12 month follow-up in Study IV. Open bars = baseline, hatched bars = three months, closed bars = 12 months. The changes from baseline to three months was statistically (categorical linear model; SAS/CATMOD) significantly greater in the AKSELI group than in the CNT group in both men (P = 0.001) and women (P = 0.001). The change from baseline to 12 months was statistically significantly greater in the AKSELI group than in the CNT group only in men (P< 0.001). P values in the figures, Wilcoxon signed rank test.

TABLE 7 Squatting and static back endurance at baseline and follow-up examinations in Study IV.

	Baseline	3-Month follow-up	Baseline vs. 3-month P^a	12-Month follow-up	Baseline vs. 12-month P^a
Squatting Men					
-AKSELI	35	67***		49**	
-CNT	42	50*	0.028	46	0.065
Squatting Women					
-AKSELI	38	72***		62***	
-CNT	32	55**	0.013	53**	NS
Static back test Men					
-AKSELI	31	43*		45(*)	
-CNT	45	49	NS	46	NS
Static back test Women					
-AKSELI	44	63***		56***	
-CNT	38	46***	NS	42**	NS

(*) $P < 0.10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$, NS = not significant, difference in comparison with the baseline examination within the group, Wilcoxon signed rank test.

[a] Statistical comparison of the change between AKSELI and CNT groups. Categorical linear model (SAS/CATMOD).

The test values indicate the percentage of subjects who obtained a "good" result. Definition of a good result: In repetition tests, the numbers of repetitions achieved by the entire subject series was divided into quintiles, and any number of repetitions above the cutoff point between the third and fourth quintile was considered a good result. The same procedure was applied to the static back test, by dividing into quintiles the extension times achieved by the entire subject series.

5.1.5 Associations between isokinetic trunk extension strength and the microscopic structure of multifidus muscles in patients with chronic low back pain (Study II)

The correlations between baseline vs. follow-up examination changes in type 2 muscle fibre size and isokinetic strength measures were not statistically significant. At baseline, there was no correlation (r = -0.05) in men and an unexpected negative correlation (r = -0.57) in women between peak torque of back extension at the slowest angular velocity and the size of type 2 fibres of the multifidus (Figure 11). At three months, a significant correlation was found in men (r = 0.74) but not in women (r = 0.16) between these parameters (Figure 12); a significant correlation (r = 0.54) was also found in men for tests at a high angular velocity (120°/s).

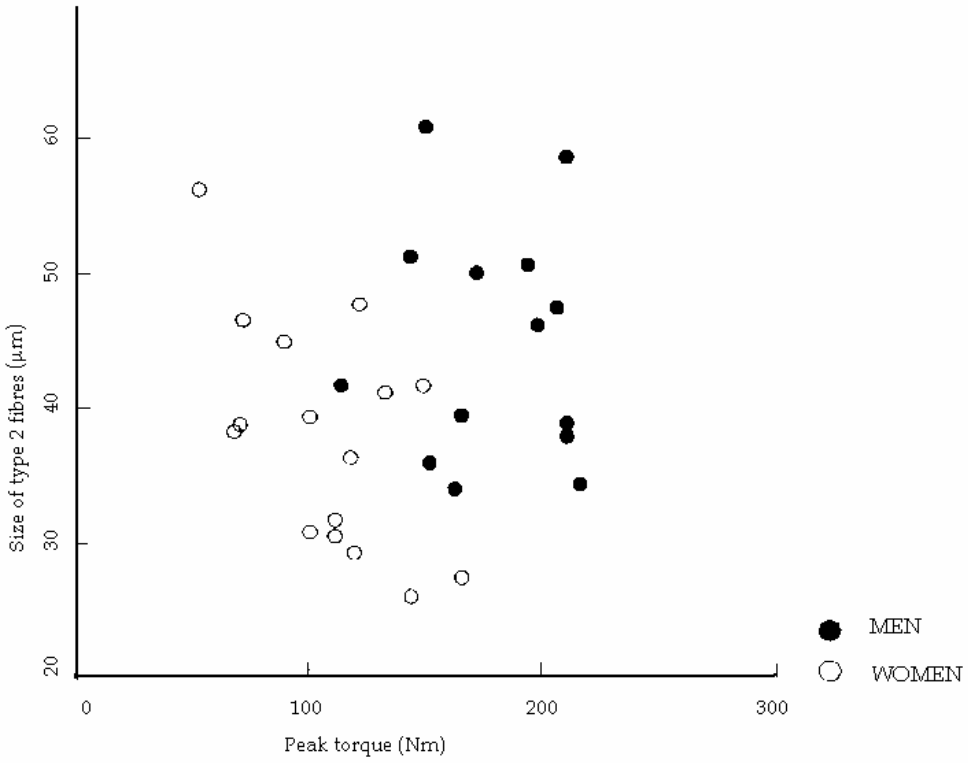


FIGURE 11 Correlation between peak torque (Nm) of trunk extension at a velocity of 30°/s and the mean lesser diameter (µm) of type 2 fibres in the multifidus muscles at baseline (r = -0.05 in men; r = -0.57 in women).

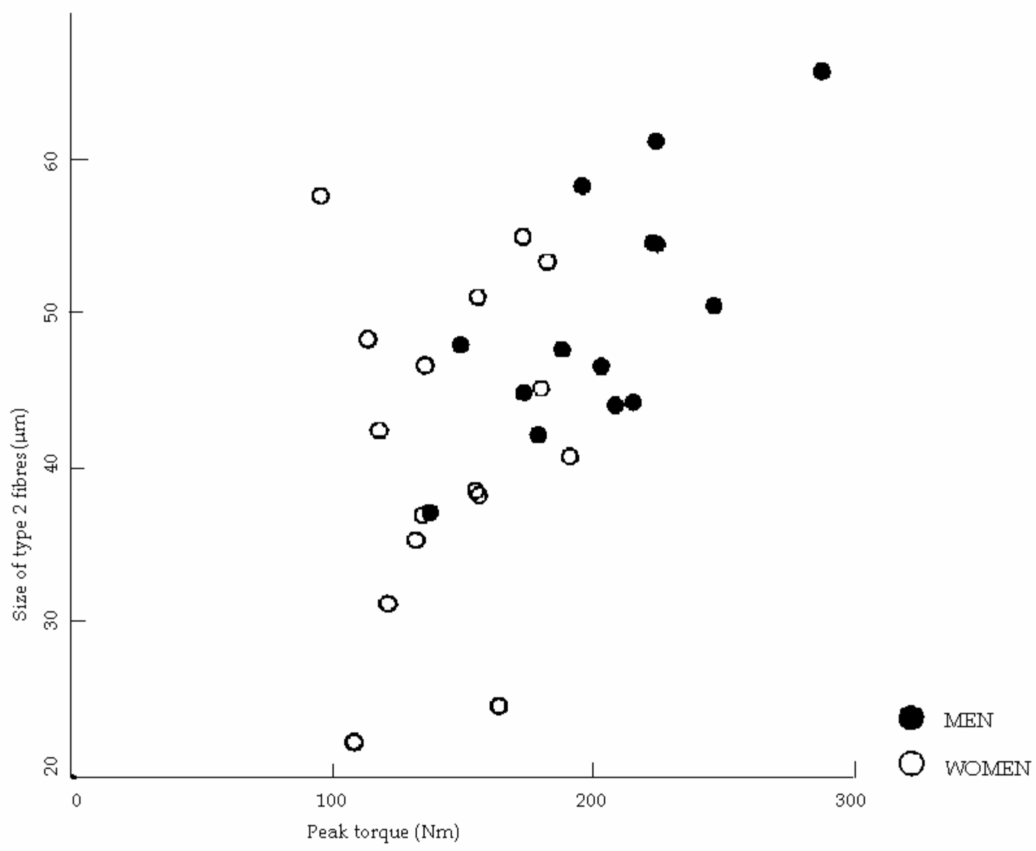


FIGURE 12 Correlation between peak torque (Nm) of trunk extension at a velocity of 30°/s and the mean lesser diameter (µm) of type 2 fibres in the multifidus muscles at three months (r = 0.74 in men; r = 0.16 in women).

5.1.6 Isokinetic and nondynamometric tests related to the Million index (Study III)

The r values and their statistical significances for the association between the Million index and isokinetic trunk flexion-extension tests are presented in Table 8. Corresponding data for nondynamometric trunk performance tests are presented in Table 9. For isokinetic tests, there was a distinct difference in r values between men and women. In women, all the parameters recorded in the isokinetic trunk flexion-extension tests were statistically significantly correlated with the pain and disability index. In men, the isokinetic trunk flexion-extension tests showed low correlation. In women, there were no differences in the correlations recorded for the angular velocities of 120°/s and 150°/s, whereas 30°/s produced a lower correlation than the former two velocities. The correlations of the various isokinetic flexion-extension performance parameters (peak torque, average torque, work, peak power and average power) with the pain and disability index were similar. Of the nondynamometric tests, the arc-up and sit-up tests in men and women and the squat test in women yielded the highest correlations. The static back endurance test had the lowest correlation of all the nondynamometric tests.

TABLE 8 Isokinetic trunk extension tests related to the Million index.

Measurement parameter	Women	Men
Peak torque		
30°/s	-0.35*** (87) †	-0.21* (95)
120°/s	-0.46*** (87)	-0.16 (95)
150°/s	-0.42*** (85)	-0.27** (94)
Average torque		
30°/s	-0.31** (87)	-0.21* (95)
120°/s	-0.43*** (87)	-0.26* (95)
150°/s	-0.44*** (85)	-0.32** (94)
Work		
30°/s	-0.32** (87)	-0.06 (95)
120°/s	-0.47*** (87)	-0.12 (95)
150°/s	-0.49*** (85)	-0.20 (94)
Peak power		
30°/s	-0.32** (87)	-0.16 (95)
120°/s	-0.46*** (87)	-0.20* (95)
150°/s	-0.44*** (85)	-0.30** (94)
Average power		
30°/s	-0.31** (87)	-0.23* (95)
120°/s	-0.41*** (87)	-0.26* (95)
150°/s	-0.41*** (85)	-0.32** (94)

† the number of subjects is given in parentheses.
The figures indicate Pearson's correlation coefficients (r) and significance levels (*P < 0.05; **P < 0.01; *** P < 0.001).

TABLE 9 Nondynamometric trunk performance tests related to the Million index.

Test	Women	Men
Repetitive sit-up	-0.46*** (89) †	-0.40*** (94)
Repetitive arch-up	-0.46*** (89)	-0.39*** (95)
Repetitive squat	-0.49*** (89)	-0.24* (96)
Static back endurance	-0.29** (89)	-0.26* (96)

† the number of subjects is given in parentheses.
The figures indicate Pearson's correlation coefficients (r) and significance levels (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$).

5.2 Activity

5.2.1 Changes in the Million index at three and twelve months (Study IV)

Both rehabilitation programmes brought a statistically significant improvement of the Million index. Nevertheless, the improvement in the Million index was clearly better in the AKSELI group than in the CNT group (17.1 vs. 9.1; $P < 0.001$) at three months and remained better at 12 months (15.9 vs. 8.9; $P = 0.011$). The results were essentially the same in men and women.

5.2.2 Changes in subjective physical performance at work and leisure-time physical activities at twelve months (Study IV)

Subjective back fitness at work and the ability to carry out strenuous leisure-time physical activities increased significantly more in the AKSELI group than in the CNT group over three months examination in both men and women. These differences were present only in males at the 12-month follow-up examination (Tables 10 and 11).

TABLE 10 Subjective work-related back performance capacity at baseline and at 12 months (%).

	No back problems at all or only in heavy tasks		Back problems in moderate physical tasks		Back problems in light physical tasks or at rest		
	Baseline	12 months	Baseline	12 months	Baseline	12 months	P^1
Men							
AKSELI (N = 66)	27	64	36	26	37	10***	0.036
CNT (N = 64)	23	47	55	33	22†	20*	
Women							
AKSELI (N = 83)	17	49	48	33	39	18***	NS
CNT (N = 74)	12	38	60	45	28	17***	

P^1 Statistical comparison of the change between AKSELI and CNT groups. Categorical linear model (SAS/CATMOD).
NS = not significant ; *P < 0.05; ***P < 0.001, difference in comparison with the baseline examination within the group. Wilcoxon signed rank test.
†P < 0.05, difference at the baseline examination between AKSELI and CNT groups. χ^2-test.

TABLE 11 Strenuousness index (0—10) of physical exercises, fitness training and leisure-time physical activities at baseline and at 12 months.

	Baseline	12 months	P^1
Men			
AKSELI (N = 66)	4.2 (1.6)*	5.9 (1.6) ***	
CNT (N = 64)	4.4 (1.6)	5.1 (1.7) **	0.05
Women			
AKSELI (N = 83)	4.8 (1.7)	6.0 (1.6) ***	
CNT (N = 74)	4.6 (1.8)	5.9 (1.3) ***	NS

* mean ± SD
P^1 Statistical comparison of the change between AKSELI and CNT groups.
Wilcoxon rank sum-test.
NS = not significant; **P < 0.01; ***P < 0.001, difference in comparison with the baseline examination within the group. Wilcoxon signed rank test.

5.3 Participation

5.3.1 Changes in use of health-care services at twelve months (Study IV)

The number of visits to doctors because of LBP during the preceding 12 months was 74% lower in the AKSELI group and 67% lower in the CNT group at 12 months compared with baseline. Both decreases were statistically significant ($P < 0.001$) but the difference between the two groups was nonsignificant. The annual number of courses of outpatient physical therapy likewise diminished significantly in the AKSELI and CNT groups by 69% and 77%, respectively. The difference between the two groups was nonsignificant.

5.3.2 Changes in sick-leave days and retirements at twelve months (Study IV)

The mean for all sick leaves during the preceding 12 months decreased from 57.8 days to 33.9 days in the AKSELI group and from 58.5 days to 36.9 days in the CNT group. There was no statistically significant difference between the groups. Over 12 months, a slightly greater proportion of patients in the CNT group retired because of back-related disability: seven of 141 subjects in the CNT group vs. four of 152 subjects in the AKSELI group (nonsignificant difference).

5.3.3 Associations between trunk extensor performance and back-related work disability during long-term follow-up (Study V)

The covariates of dynamic trunk extension performance were studied in the cross-sectional setting of the baseline health examination. A number of factors independent of the two most powerful covariates, age and sex, were significantly associated with dynamic trunk extension performance and were thus potential confounders of the association between trunk extension performance and risk of disability.

The overall incidence of work-related disability was 8.5 per 1000 person-years. Of the 56 incident cases of work-related disability, 15 were due to back disorders. As adjusted for age and sex, dynamic trunk extension performance at baseline was strongly predictive of work-related disability caused by chronic low back disorders but not of disability caused by other diseases. Low education, previous episodes of LBP and the presence of CLBP at baseline were significant predictors of back-related disability. Body mass index, heavy labour, smoking and lack of leisure-time physical activity also appeared to carry predictive value, but the associations with back-related disability did not reach statistical significance after adjustment for age and sex.

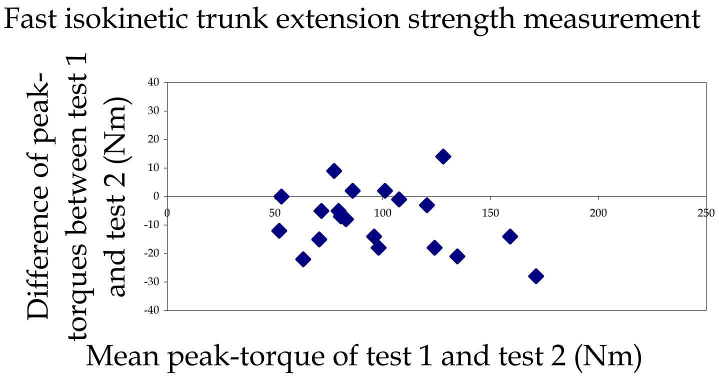
TABLE 13 Adjusted relative risks and 95% confidence intervals of permanent work-related disability caused by back disorders for quartiles of trunk extension performance.

			Model 1†		Model 2‡	
Quartile* of trunk extension performance	Subjects (N)	Incident cases (N)	Relative risk	95% confidence interval	Relative risk	95% confidence interval
I (lowest)	106	9	1.00		1.00	
II-IV§	429	6	0.18	0.06-0.55	0.28	0.09-0.94
P for heterogeneity			0.002		0.04	

* The cutoff points were 12, 16, 19 and 30 repetitions of trunk extension in 30 s for men and 9, 12, 16 and 24 repetitions for women.
† adjusted for age and sex
‡ adjusted for age, sex, body height, body mass index, education, physical labour at work, mental stress at work, physical activity at leisure, smoking, history of LBP, chronic disabling diseases and trunk flexion performance
§ one, four and one incident cases in quartiles II, III and IV, respectively

As entering the quadratic term of dynamic trunk extension performance into Cox's model suggested a nonlinear association with the risk of permanent work-related disability caused by back disorders (P = 0.12 for departure from linearity), the dynamic trunk extension performance data were divided into quartiles. The relative risk was significantly reduced from the second quartile up, but all the quartile-specific risk estimates were unstable, perhaps because of the small number of incident cases in each quartile. The relative risk of back-related disability between the lowest quartile and higher quartiles of dynamic trunk extension performance remained statistically significant when the risk of work-related disability was adjusted for all the potential confounders (Table 13).

5.4.1 Bland-Altman plots of isokinetic trunk extension peak torque test-retest measurements



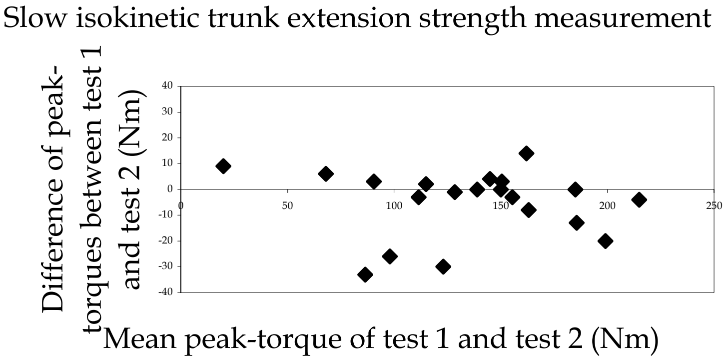


FIGURE 13 Test-retest results of isokinetic trunk extension peak torque measurements in 20 healthy subjects. Bland-Altman plots at fast (150°/sec) and slow (30°/sec) angular velocities.

6 DISCUSSION

6.1 Study design and methods

6.1.1 Subjects and study design

STUDY I: The study material comprised 21 cadavers (14 male, seven female) of people who had died suddenly. For ethical reasons, the family members of the cadaver subjects were not enquired about the subjects' history of CLBP. Recurrent low back pain is common among the general population (Heliövaara et al. 1989), and minor or rapidly improving symptoms may not require medical attention. Therefore, the present cadaver subjects, whose medical records contained no mention of back symptomatology, may still have had mild back symptoms. It can nevertheless be assumed from the absence of back symptom data in the medical records of these subjects who died suddenly that any back pains that the subjects may have had must no doubt have been considerably less intensive and less frequent compared with those people who have been granted an inhouse rehabilitation period specifically for long-term back symptomatology. The intensity of premortem physical activity, which might have affected the muscle structure, could not be determined in these cadaver subjects.

Previous cadaver studies have been based on small populations: two males and one female in the study of Fidler (1975), nine males and three females in the study of Mattila and coauthors (1986), six young males in the study of Johnson and coauthors (1973), 21 males in the study of Širca & Kostevc (1985) and 10 young healthy men and six young male cadavers in the study of Jørgensen and coauthors (1993). The structure of back muscles of living women and men has been reported in one study, but all of these subjects were 30 years of age or younger (Thorstensson & Carlson 1987). After the present autopsy study, Mannion and coauthors (1997) analysed muscle samples from the thoracic and lumbar region of 17 healthy men and 14 healthy women volunteers, but these subjects, too, were physically active, young people (mean age 23.0 years in men and 29.4 years in women).

The present study differs from other reports in that multiple sampling sites were used, allowing comparison between lumbar iliocostalis and multifidus muscles and between different sites in the multifidus muscle group. As there were more subjects in the present series than in other studies except one (Mannion et al. 1997), and the age range was wider (23 to 65 years, mean 44.7 years) than in other studies, and both sexes were included, this study would appear to better represent the working-age population than do the other available reports.

STUDY II: The effects of an intensive physical rehabilitation programme on the structure and strength of lumbar and leg muscles of CLBP patients were studied in a longitudinal follow-up setting using muscle biopsies and isokinetic strength tests. The subjects (14 men and 16 women) had CLBP, were 30 to 47 years of age and had been referred rehabilitation. In spite of the absence of a control group, the longitudinal follow-up setting and low dropout rate made it possible to detect changes in muscle structure and isokinetic strength produced by the intensive strength training programme. The present study appears to have been the first investigation into the effects of training on the structure of lumbar and leg muscles in CLBP patients.

STUDY III: This study examined the association of isokinetic and nondynamometric test performance with subjective LBP and disability. The subjects of the study were a subsample from Study IV and comprised 185 patients with CLBP. All the subjects had received rehabilitation in either the AKSELI or the CNT Programme. They took isokinetic trunk strength tests and nondynamometric repetitive tests in conjunction with the 12-month follow-up examination of the rehabilitation study (Study IV). It would have been preferable to do the measurements for Study III at baseline before the rehabilitation programmes, but the isokinetic tests were not available to all patients at baseline.

STUDY IV: This study was a randomised, controlled, clinical trial comparing an intensive inhouse rehabilitation programme (AKSELI Programme) including psychosocial support with a conventional, physically less intensive inhouse rehabilitation programme (CNT Programme). It is an unfortunate shortcoming of the present study that instead of a sham programme the control group underwent the CNT Programme which was the current rehabilitation method applied at the five rehabilitation institutes at the time of the study. Moreover, the institutes were given no advance instructions on the amount of physical training or passive physiotherapy to be administered to the control subjects of the present study. This problem was dealt with by recording the total duration of physical exercise performed by each member of the CNT group during the inhouse rehabilitation period. Even though 85 patients were excluded at baseline mainly because of contraindications for heavy physical exercise, the AKSELI group and the CNT group did represent typical CLBP patients of 30 to 47 years of age, who had work-related health problems, and who had not applied for disability pension and were capable on the basis of their health status to undertake intensive physical exercises. The dropout rate also remained exceptionally low for an intervention study: only 2% in both groups at 12 months.

STUDY V: The subjects took dynamic trunk muscle endurance tests at baseline, after which they were monitored for disability retirement. The subjects of this study came from a random subsample of the comprehensive Mini-Finland Health Survey (Figure 6). The eligible 535 subjects remained in the study population. Although the study population was a random sample, it can be speculated that the high number of exclusions diminished the confounding effect of motivation. On the other hand, the excluded persons, who had cardiovascular risks or other chronic diseases or refused the trunk muscle tests, can be assumed to have been in poorer physical condition than those who participated in the study. Thus, the high number of exclusions was not a critical disadvantage, as it only brought about a more conservative estimate of the association between trunk extension capacity and the risk of back-related work disability.

6.1.2 Muscle biopsies and measurements of histomorphology

Ethical considerations were the main reason for using necropsies to study the microscopic structure of back muscles in a population without back disorders. It is has been reported that rigor mortis can expand fibre diameter in muscle samples from cadavers (Shorey & Cleland 1988). In contrast, the muscle fibres of mice appear to decrease in size after death (Rowe & Goldspink 1969, Hegarthy & Hooper 1971). The latter finding is supported by a literature review on studies of human muscle fibre size in living and autopsy subjects (Ng et al. 1998), in which both type 1 and type 2 fibres were invariably found to be smaller in studies of cadavers than in studies of living subjects. Although samples from cadavers may thus differ from muscle biopsies taken from living subjects, there is evidence that postmortem changes will affect equally type 1 and type 2 fibres, with no shift in their relative sizes after death (Shorey & Cleland 1988). When comparing different muscle biopsy studies, it should be borne in mind that differences in histological processing (fresh-frozen, fixed-frozen, celloidin-embedded or paraffin embedded specimens) also may affect the results (Moore et al. 1971, Shorey & Cleland 1983).

Muscle fibres are highly adaptable, and innumerable fibre type transients will therefore exist, and some muscles (masticatory and extraocular) will also contain isoforms or combinations of myosin heavy chains that do not fit the ATPase-based fibre classification (Staron 1997). Within types 1 and 2, there are fibre subtypes (1C, 2A, 2B, 2AB, 2AC) identifiable by the ATPase method (Staron 1997). Each of these fibre types has a specific myosin heavy chain profile which determines the physiological properties of the muscle fibre. Possible alterations in the frequencies of the several fibre subtypes caused by strength training were not investigated in this study.

The question can be asked whether the multifidus muscle is the most representative biopsy site to study the effects of training on back muscles. The multifidus was chosen for the present study on the basis of a previous back muscle biopsy study (Mattila et al. 1986). Subsequently, the multifidus muscle has been shown to be useful for studying the effects of training on back muscles. Arokoski and coauthors (1999) studied EMG amplitudes in different trunk muscles of healthy volunteers during 18 trunk muscle exercises. They demonstrated higher activation of the multifidus than of the longissimus during the exercises. This finding warrants the conclusion that any structural changes in back muscles induced by trunk muscle training would most certainly be apparent in the multifidus. In the present study, samples were also obtained from the vastus lateralis muscle for comparison with the multifidus.

There will always be biological variation in muscle fibre size or fibre distribution between different sampling sites in a muscle. As a solution to this problem in single needle biopsies, Lexell & Taylor (1989) suggested that more than 100 fibres be analysed in the sample. To get a consistent value for the mean diameter and a low SD value, Dubowitz (1985) measured 200 fibres per sample. With a view to minimising sampling errors, the approach proposed by Dubowitz was adopted in the present study. The mean numbers of fibres analysed for each CLBP patient were 235 (SD 33) and 218 (SD 39) at baseline and 225 (SD 33) and 225 (SD 57) at follow-up in the multifidus and vastus lateralis muscles, respectively. The mean number of fibres analysed for each cadaver was 286 per muscle sample (range 179—390).

6.1.3 Measurements of muscle performance

Maximum trunk flexion and extension strength was measured with isokinetic dynamometric tests which provide numerical results on torque, power and work. In the present study, none of these parameters could be shown to be superior in evaluating CLBP patients' trunk muscle performance (Study III), and thus peak torque, as a commonly used measure, was chosen as the parameter of isokinetic trunk extension performance for this study.

The consistency of peak torques measured by isokinetic devices has been previously demonstrated (Smith et al. 1985). Also prior to the present study, Jacobs & Pope (1986) studied the consistency of the Ariel 4000® dynamometer used in the present study. In addition, new intratester and intertester analyses were performed in the present study because a new pelvis and leg stabilisation system was built for the dynamometer to allow measurements of trunk movements with the subject standing. With the new construction, the r value between isokinetic trunk strength tests varied between 0.82 and 0.95 (unpublished data: Sainio 1994), which concurs with the correlations observed ($r = 0.80—0.97$) for another isokinetic device, as reported by Grabiner and coauthors (1990). A Bland-Altman plot on isokinetic trunk extension peak torque (Figure 13) showed, however, that the measurement consistency was insufficient to detect individual-level changes in muscle strength induced by exercise. In addition, a learning effect was evident in the Bland-Altman plot for isokinetic trunk extension measurements. Although the test-retest analyses of isokinetic strength tests implicated that it was impossible at the level of the individual to conclude whether a change in peak torque was caused by muscle training or coincidence, Friedlander and coauthors (1991) have shown that even minor changes in strength can be detected with statistical confidence if a group of 10 subjects, for example, is examined.

Dynamometric measurements have been criticised for several reasons (Newton & Waddell 1993). It has been argued that trunk movement at a constant angular velocity is not physiological. That is certainly true, but the most important consideration for trunk strength measurements in the present study was sufficient consistency, and no other method appeared to be superior to the isokinetic dynamometer in this respect. A systematic learning effect is always a problem in strength measurements, the isokinetic method being no exception. An effort was made to diminish the learning effect by accustoming every subject to the isokinetic test by doing a "practice run" before the actual baseline test. As subjective disability and pain expression can affect isokinetic dynamometry testing in patients with CLBP (Hupli 1998, Ohnmeiss et al. 2000), care must be taken to relate the test results directly to muscle performance.

Hupli and coauthors (1997) compared the isokinetic strength values of 20 healthy and 21 LBP subjects measured with two different isokinetic devices and found that strength tests made with different isokinetic devices are not automatically comparable. The entire test protocol may also vary in many ways among different studies (Newton & Waddell 1993). For instance, the number of repetitions, the rest period between efforts, the level of the axis of movement, the length of the moment arm and also the amount of verbal support given by test personnel can differ even between studies done with similar dynamometers. It seems obvious that absolute isokinetic strength values will be specific to each study and their direct comparison between studies impossible.

6.1.4 Measurements of activity and participation

Most questions (Appendix 1) in the Million index of subjective pain and disability measure perceived performance of the subject at different tasks in everyday life. Even though the Million index includes a strong aspect of pain perception, it logically belongs in the domain of activity in the ICF framework. The consistency of the Million index has been demonstrated (Alaranta et al. 1990) but no studies assessing the smallest clinically relevant change in this index have been reported. Subjective physical performance at work and strenuousness of leisure-time physical activities also represent perceived performance, thus being items of activity rather than of participation under the ICF. Sick leaves and retirements are multidimensional phenomena but are naturally associated with the domain of participation. Health care use as an outcome measure is difficult to assign an ICF category, but especially in the case of CLBP patients a diminished use of health care services after rehabilitation would seem to demonstrate the patients' increased participation in the self-care of their back disorders instead of relying on physicians or physiotherapists.

6.1.5 Targets and doses of strength exercises in back rehabilitation

Patients with CLBP are generally considered to be at risk for deconditioning, which has prompted the formulation of many kinds of physical exercise programmes. Trunk muscle exercises have assumed a central part in most back rehabilitation programmes. Physical exercise may also support psychological, sociological and environmental therapy modalities in the rehabilitation framework (Mälkiä & Kannus 1996). Also lumbar motor control, proprioception and postural control have been recently studied in LBP patients with sciatica and lumbar spinal stenosis (Leinonen 2003). According to a randomised study, programmes designed to train mainly muscular endurance and co-ordination reduced pain and self-reported disability in patients with CLBP (Kankaanpää et al. 1999). Specific exercises for motor control have also been recommended for patients with CLBP (Luoto et al. 1996, Kuukkanen & Mälkiä 1998). It has been also speculated that physical exercise could have direct positive effects on intervertebral cartilaginous tissue (Vanharanta 1994). These topics are beyond the scope of the present study, however.

Although clinical diagnostic criteria and diagnostic imaging methods continue to be a controversial issue in spinal instability, and the phenomenon of clinical instability syndrome is still poorly understood (Fritz et al. 1998), advances have been made during the past two decades in understanding the sensorimotor control of the spine. Lumbar afferents have nerve endings in the outer annuli of intervertebral discs, in the capsules of zygapophysial joints and in ligaments of the spine. It seems that these afferents not only relay sensory information but also control trunk muscles through a reflex system and probably provide kinesthetic perception to the sensory cortex (Holm et al. 2002). According to Panjabi (1992), spinal stability is dependent on three subsystems: (a) vertebrae, discs and ligaments; (b) muscles and tendons; and (c) nerves and the central nervous system. Experimental studies support the vital role of the neuromuscular system in the stabilisation of the spine (Panjabi et al. 1989, Crisco et al. 1992, Wilke et al.1995). A good example of the co-operation of different stabilising subsystems was reported by Claude and coauthors (2003) who observed creep of the passive spinal tissues and high reflex activity leading to hyperexcitability and spasms in the multifidus muscles as a result of passive cyclic flexion of the feline lumbar spine. This finding may provide a biomechanical and neurophysiological explanation for the high rate of LBP in workers doing repetitive lumbar flexion.

In studies in vitro, it was demonstrated that different muscle groups stiffened the motion segments of the lumbar spine, with the strongest influence being exerted by the multifidus muscle (Wilke et al.1995, Quint et al. 1998). In an experiment in vivo, Cholewicki & van Vliet (2002) found that the stability of the spine depends on the relative activation of all trunk muscles and that one muscle group could explain at most 30% of the spinal stability created by muscle tension. According to van Dieën and coauthors (2003), differences in trunk muscle recruitment patterns between healthy subjects and CLBP patients are likely to be functional with respect to enhancement of spinal stability in patients.

In a study in power lifters, Cholewicki and McGill (1992) made the unique finding that LBP was caused by excess rotation in a single lumbar joint as a result of inappropriate sequencing of muscle forces during lifting. It seems plausible that weak back muscles in relation to spinal load or inadequate motor control of the trunk muscles diminish the stability of the lumbar spine and predispose to accumulative microtraumas in spinal structures and to subsequent CLBP. Based on biomechanical studies and trunk muscle strength studies in patients with CLBP, it would appear a rational target for muscle training in back rehabilitation to aim for better stability of the lumbar spine in different movements, positions and loading situations

The response to dynamic resistance training is mainly determined by the dosage (loads, numbers of repetitions) and duration (number of sessions) of the exercises. The right dose of exercise for CLBP patients is difficult to estimate because safe and non-pain-provoking training at low loads has no strengthening effect while too high loads or a too long duration may exceed the failure tolerance of the patient's spinal tissues (McGill 1997, Callaghan et al. 1998) and lead to worsening of LBP. Whereas there are no reports of harmful effects of exercise in patients with CLBP, there is evidence that therapeutic exercise does not increase future LBP episodes or work absence (Rainville et al. 2004b). No dose-response analyses have been reported that assess the total physical loading of subjects, both at work and during leisure-time. In many back rehabilitation studies, exercise dose and duration are given inadequate attention (Manniche & Jordan 1995). Dose-response relationships have been reported for two intensive exercise programmes and one light exercise programme in CLBP patients (Manniche et al. 1988, Manniche et al. 1991). All the parameters measuring patients' overall assessment, pain, physical fitness and activity significantly favoured the exercise programme with the highest training dosage. Danneels and coauthors (2001) studied the effects of three training modalities of 10 weeks' duration on the cross-sectional area of the paravertebral muscles in patients with CLBP. They found no effect on the cross-sectional area of the lumbar muscles with less intensive "stabilisation training" whereas "stabilisation training" in combination with more intensive dynamic resistance training produced a significant increase in the cross-sectional area of these muscles. In a review article, Guzmán and coauthors proposed an overall duration in excess of 100 h for an effective multidisciplinary programme (Guzmán et al. 2001). The AKSELI Programme of the present study exceeded the recommendation of Guzmán and coauthors. Based on the few above mentioned reports in which exercise dose and duration have been adequately described (Manniche et al. 1988, Manniche et al. 1991, Danneels et al. 2001), it appears evident that the loads, duration, frequency and the length of the training period in the AKSELI Programme were sufficient to improve back muscle strength and induce muscle hypertrophy.

6.2 Results

6.2.1 Microscopic structure of lumbar muscles in subjects without back disorders

There was a clear predominance of type 1 fibres (57.4—69.6%) in the iliocostalis and multifidus muscles in the present study. The predominance of type 1 fibres in lumbar muscles has also been reported by other investigators (Širca & Kostevc 1985, Jørgensen et al. 1993, Mannion et al. 1997). This is in accordance with previous reports suggesting that muscles with a postural function will contain predominantly fibres of type 1 (Susheela & Walton 1969, Jennekens et al. 1971, Polgar et al. 1973). Back muscles have much greater potential than any other skeletal muscles for developing isometric endurance (Jørgensen et al. 1993). Mannion and coauthors (1997) also compared the size of muscle fibres between the thoracic and lumbar erector spinae in healthy young subjects. Interestingly, they found that both type 1 and type 2 fibres were significantly larger in the thoracic region than in the lumbar region. They concluded that this may reflect adaptive responses to differences in function of muscle fascicles in the thoracic and lumbar erector spinae.

In the present study population (mean age 44.7 years), type 2 fibres were significantly smaller than type 1 fibres at all sites in the lumbar multifidus and iliocostalis muscles. This deviates from the results of a biopsy study in younger subjects where essentially no difference in size between type 1 and 2 fibres in lumbar muscles was found (Jørgensen et al. 1993). According to Mannion and coauthors (1997), type 2 fibres were smaller than type 1 fibres in the lumbar muscles of healthy young women, whereas the fibre types were similar in size in young men. Previously, Thorstensson and Carlson (1987) had found type 2 fibres to be even larger than type 1 fibres in the back muscles of healthy young men. A study in 21 male autopsy subjects of 22—46 years of age found type 1 fibres to be larger than type 2 fibres (54.8 μm and 41.6 μm, respectively) in the deep multifidus at the level of the LIII vertebra (Širca & Kostevc 1985), which is similar to but not quite as striking as the difference seen in the present study. In the present study, the diameter of type 2 fibres also differed significantly between men and women while there was no gender-related difference in the lesser diameter of type 1 fibres. The gender-related difference in the size of type 2 fibres, which seems to increase with age, may be explainable by differences in strenuousness of physical activities between men and women.

There were no significant differences in fibre distribution or fibre size in the present study between the iliocostalis and multifidus muscles or among different vertebral levels of the multifidus muscle in subjects without known back disorders. The situation was similar between surface and deeper sampling sites in the multifidus muscle. The results of the present study provide reference values with which the distribution and size of the main fibre types in muscle samples from CLBP patients can be compared, keeping in mind the potential effect of postmortem shrinkage of muscle fibres in autopsy samples. Based on the findings of the present study and other reports (Fidler et al. 1975, Širca and Kostevc 1985), it can be concluded that selective type 2 fibre atrophy in lumbar muscles is common not only in patients with CLBP but also in sedentary individuals with the possible exception of young people. Regarding young people, Salminen and coauthors (1993) found physically inactive 15-year-olds to have significantly smaller paraspinal muscles on magnetic resonance imaging than subjects of the same age who were physically more active.

6.2.2 Microscopic structure of multifidus and vastus lateralis muscles in patients with chronic low back pain

There was a predominance of type 1 fibres in the multifidus muscle in both men (68%) and women (65%) with CLBP at baseline, resembling the situation in autopsy subjects without back disorders. In the vastus lateralis muscles of CLBP patients, the situation was reversed with type 1 fibres being in a minority in both men and women (47% and 49%, respectively). This was expected on the basis of the dynamic function of leg muscles and a previous report with the proportion of type 1 fibres ranging from 45.5% (surface biopsy) to 46.6% (deep biopsy) in six male autopsy subjects (Johnson et al. 1973).

The mean lesser diameters of type 1 fibres were similar in the multifidus and vastus lateralis muscles in CLBP patients. The mean lesser diameter of type 1 fibres in the multifidus was significantly bigger than that of type 2 fibres. There was no atrophy of type 2 fibres in the vastus lateralis muscle in men or women. Muscle fibre atrophy in the lumbar muscles of CLBP patients may be caused by pain avoidance and inactivity. Disuse atrophy of human skeletal muscle affects type 1 and type 2 fibres to a similar degree (Häkkinen et al. 1981, Lindboe & Platou 1982).Why type 1 fibres in the multifidus of CLBP patients in the present study had retained their size or were even bigger than in autopsy subjects may be partly explained by long-standing back muscle spasms induced by LBP (Mattila et al. 1986). It should be borne in mind, however, that part of the difference in fibre size between living subjects and cadavers may be caused by postmortem shrinkage.

Crossman and coauthors (2004) recently reported no atrophy of type 1 or type 2 fibres in the paraspinal muscles of either healthy men or men with CLBP (overall age range 18—55 years, mean age 38—41 years in different groups). The marked disparity in terms of the size of type 2 fibres between Crossman and coauthors (2004) and the present study, and also the study of Širca & Kostevc (1985), may be ascribed to differences in study population. In the former study, the population of CLBP patients was represented, for instance, by male physiotherapists with CLBP, and the most severely disabled patients were excluded from the study. Normal controls consisted of volunteers from among hospital staff. It appears likely that the subjects of Crossman and coauthors (2004) were physically more active than typical CLBP patients or typical sedentary men without CLBP.

According to Jørgensen (1997), trunk extensor strength has been substantially reduced during the past two or three decades, even in healthy people. This together with the muscle biopsy results in autopsy subjects and CLBP patients in the present study supports the conclusion that sedentary life style was the reason for the selective type 2 fibre atrophy found in the back muscles of both healthy subjects and CLBP patients.

Weak leg extensors have been associated with a history of low back problems and back-related sick leave in young men (Karvonen et al. 1980). Lee and coauthors (1995) found similar weakness in CLBP patients' quadriceps muscles as in their back muscles. In contrast to these findings, there was no muscle fibre atrophy in the vastus lateralis muscles of CLBP patients in the present study. This may be explained by the fact that even CLBP patients activate their vastus lateralis muscles in everyday life more dynamically and more frequently at higher muscle tension levels than their back muscles.

6.2.3 Exercise-induced changes in the strength and fibre size of back and leg muscles in patients with chronic low back pain

Men and women increased their trunk extension strength by 14% and 33%, respectively, at the angular velocity of 30°/s over three months. Corresponding increases at the angular velocity of 120°/s were 16% and 23%. Correlation has been demonstrated between the peak torque produced at the highest speed of muscle shortening and the proportion and relative area of type 2 fibres in the contracting muscle (Thorstensson et al. 1976). In the present study, there was no correlation between multifidus muscle fibre size and isokinetic trunk extension strength at baseline either in men or women. After the AKSELI Programme, the size of type 2 fibres of the multifidus of men correlated moderately with the isokinetic strength of back extension at angular velocities of 30°/s and 120°/s. This change may originate in CLBP patients having had a reduced capacity to voluntarily recruit their multifidus muscles at baseline (Danneels et al. 2002).

After rehabilitation, the ability to activate back muscles to maximal or near maximal contraction was markedly improved in men. According to Mannion and coauthors (2001b), rehabilitation may improve trunk muscle performance mainly through enhanced neural activation and possibly through psychological effects. In contrast to men, women showed no correlation between type 2 fibre size in the multifidus and back extension strength at baseline or at three months. It seems obvious that men with CLBP were able to recruit their back muscle fibres closer to their maximal physiological level after the AKSELI Programme. Momentary pain experiences of each individual were recorded on a visual analogue scale during the strength test procedure. No correlation was found between pain and peak torque at each test session or between the three-month change in pain and peak torque. Thus, the above-mentioned differences between men and women cannot be explained by gender-related differences in pain sensation. Nevertheless, the endocrine response during few weeks heavy strength training might favour men more than women (Kraemer 1992, Raastad et al. 2001).

Knee extension strength improved much less than trunk extension at both angular velocities (7% and 5% in men and 18% and 9% in women). This is probably due to better fitness of leg muscles than back muscles at the baseline examination.

The physical exercises of the AKSELI Programme produced a significant increase in the size of type 2 fibres in the multifidus (11%) and vastus lateralis (8%) muscles of men. In women, the corresponding increases in the multifidus (11%) and vastus lateralis (11%) reached statistical significance only in the case of vastus lateralis. The exercises did not increase the size of type 1 fibres in the multifidus or vastus lateralis muscles either in men or women. In contrast to these findings, it has been reported that a 10-week strength training programme can increase the size of both type 1 and type 2 fibres in both young and older healthy men (Häkkinen et al. 1998). The present finding may derive from the fact that the type 2 fibres of CLBP patients were smaller than type 1 fibres at baseline particularly in the multifidus but also in the vastus lateralis, and type 2 fibres being therefore more prone to hypertrophy as a result of strength training. Women had similar trend for enlargement of type 2 fibres in the multifidus, but they might have needed much longer training period or more intensive exercises to achieve significant changes in the multifidus.

Käser and coauthors (2001) studied the effects of active physiotherapy, resistance training and aerobics on fibre size in the iliocostalis lumborum muscle of CLBP patients in a randomised trial. Although three months of training did not change the diameter of either type 1 or 2 fibres in back muscles, there are two major differences compared with the present study. Firstly, type 2 fibres were found to be atrophic in the subjects of the present study at baseline, whereas type 2 fibres were in much better shape in the study of Käser and coauthors . It is well known that the stronger the muscle the more resistant it will be to fibre hypertrophy induced by training. Secondly, Käser and coauthors applied resistance programme in which the loads in back muscle strength training were lower and the weekly training sessions much fewer than in the present study.

Exercise-induced changes in the distribution of type 1 and type 2 fibres in the multifidus and triceps brachi muscles have been found in animal studies (Puustjärvi et al. 1994). In the present study, no significant changes in fibre distribution (type 1 and type 2) in the multifidus or vastus lateralis muscles were observed as a result of the training programme.

6.2.4 Association of the pain and disability index with isokinetic trunk tests and nondynamometric tests

All isokinetic trunk extension and flexion test parameters in women with CLBP were significantly correlated with the Million index. This is in agreement with the study of Ohnmeiss and coauthors (2000) who found isokinetic trunk strength tests in LBP patients to be significantly influenced not only by muscle fitness but also by patient's disability (Oswestry) index and pain drawings. In the present study, however, all the correlations were low among men. Hurri and coauthors (1995) also found a similar gender-related difference in the association of the disability (Oswestry) index with isokinetic trunk strength measurements. Isometric back extension and flexion strength tests have been reported to be only slightly correlated with the pain and disability index in both men and women suffering from CLBP (Rantanen 2001). In the present study, no single isokinetic parameter (peak torque, average torque, work, peak power, average power) exceeded the others in its correlation with the pain and disability index. The most commonly used measure, peak torque, can therefore be safely applied even in the future as the main muscle performance parameter in isokinetic trunk tests in CLBP patients.

In contrast to the isokinetic trunk flexion-extension tests, both men and women showed significant correlations between the repetitive sit-up, arch-up and squat tests and the Million index in the present study. Grönblad and coauthors (1994) also reported correlations of arch-up and squat tests with perceived disability, with the sit-up test failing to reach statistically significant correlation after adjustment for age and sex, however. Static back endurance showed the lowest correlation of the nondynamometric tests in the present study, which contrasts with the results of Hurri and coauthors (1995). The latter authors found a significant inverse correlation of -0.54 between perceived disability and static back endurance in women after rehabilitation.

Isokinetic strength measurement has been shown to be sufficiently consistent to detect small changes in the maximal strength of limb and trunk muscles in a group of subjects (Delitto et al. 1991, Friedlander et al. 1991). Isokinetic trunk flexion-extension measurements are suited for scientific uses requiring accurate numerical results and easy detection of the differences in performance (Hupli 1998). Nevertheless, both the present study and the study of Hurri and coauthors (1995) failed to come up with any new benefits of the rather expensive isokinetic equipment in the practical evaluation of function in CLBP patients. The results of the present study together with the observations of Grönblad and coauthors (1994) show that nondynamometric repetitive tests still play a useful role in the clinical evaluation of patients with CLBP. It is worth noting, however, that repetitive tests do not measure maximal strength but merely aspects of dynamic endurance.

6.2.5 Effects of intensive rehabilitation on the trunk muscle function, activity and participation of patients with chronic low back pain

One of the main aims of the present study was to investigate the effects of exercise programmes of different intensities on trunk muscle performance in CLBP patients. The subjects' performance in repetitive sit-up, arch-up and squat tests, all of which measure dynamic endurance, improved significantly more with physically intensive rehabilitation (AKSELI) than with less intensive rehabilitation (CNT) over three months. Kohles and coauthors (1990) found that an intensive strength exercise programme significantly improved the isokinetic trunk muscle strength of CLBP patients with a history of an average of 11 months of absence from work, but the trunk strength level of healthy subjects was not achieved. Mellin and coauthors (1993) reported improvements in isometric trunk extension strength of 35% in men and 51% in women at the end of an intensive four-weeks inhouse exercise programme for patients with CLBP. Pain-related fear has been shown to be directly associated with reduced lumbar flexion range and abnormalities in surface EMG of back muscles in CLBP patients (Geisser et al. 2004). According to Rainville and coauthors (2004a), intensive exercises administered in a group setting can diminish two types of exercise-associated back pain: that anticipated before physical activities and that induced by physical activities.

Part of the improvement in trunk muscle performance in the present study can undoubtedly be explained by learning, psychological processes such as desensitisation of fears related to LBP and altered attitudes and beliefs concerning pain (Risch et al. 1993). In addition, of course, there was improvement of trunk muscle activation and enlargement of type 2 fibres in back and leg muscles particularly in men (Study II). At 12 months, the difference in performance between the more and less intensive training groups was retained only among men. In women, the difference between the two groups remained only with regard to the sit-up test at the 12-month follow-up examination. This is in accordance with the conclusion drawn in the review article of Mälkiä & Ljunggren (1996) whereby men may obtain greater benefit from exercise programmes than do women.

Activity of the subjects in the present study was measured by the Million index and leisure-time physical activity. The Million index improved significantly in both the AKSELI group and the CNT group. The improvement was significantly greater in the AKSELI group at three months, and a similar trend was still found at 12 months. The difference between men and women in the present study was also reflected in leisure-time physical activities at the 12-month examination, with these activities being more strenuous in the AKSELI group than in the CNT group only among men.

Pain reduction and improvement of back function have been reported in several studies of intensive physical training combined with behavioural support (Mayer et al. 1985a, Manniche et al. 1988, Hazard et al. 1989, Lindström et al.1992, Mellin et al. 1993). Recently Liddle and coauthors (2004) reviewed studies incorporating trunk strengthening or stabilisation exercises and found evidence for improvement of back–specific function in programmes including supervised exercise. The exact reason for improvement of back-specific function in different programmes is obscure. Indeed, there may be several factors in rehabilitation that can reduce pain and subjective disability. In the present study neither the improvement in the isokinetic peak torque of trunk extension nor the increase in the size of type 2 muscle fibres in the multifidus was statistically associated with the improvement in the Million index. This is in line with the study of Mannion and coauthors (2001a) in which the improvement in CLBP patients' functioning after active therapy was related only to reductions in pain, psychological distress and fear or avoidance behaviour but not at all to improved physical performance. Penttinen and coauthors (2002) observed that the social interaction among CLBP patients during the course of a back school programme helped to lower the score of perceived disability in both sexes, particularly in men. According to Talo (1992), functioning in CLBP is also determined by the age and sex of the patient.

The intensive rehabilitation programme of the present study was not able to improve CLBP patients' participation, as measured by the number of sick-leave days, any more than the less intensive programme at the 12-month follow-up examination. Ljunggren and coauthors (1997) reported that two different exercise programmes reduced work absenteeism significantly and quite similarly (75—80%) over 12 months. Bendix and coauthors (2000) also found no significant difference in work absenteeism between a comprehensive functional restoration programme and an outpatient programme involving intensive physical training. Järvikoski and coauthors (1993) compared two multimodal back rehabilitation methods including exercise regimens of different intensity. It turned out that subjects who had performed intensive exercises had better functional capacity and less pain at 12 months but no less sick leaves than those in the less intensive programme. Conversely, Storrø and coauthors (2004) reported a significant reduction in sick-leave days in favour of a multidisciplinary rehabilitation programme, compared with ordinary treatment of CLBP without rehabilitation. It therefore seems that the mode, intensity, frequency and duration of rehabilitation in CLBP patients have little influence on sick leaves, while rehabilitation programmes in general may afford benefits over conventional treatment without rehabilitation in terms of work ability.

There were very few retirements caused by back-related disability after one year, and the difference between the two groups was statistically nonsignificant. As the subjects in the present study were 30 to 47 years of age, it can be speculated whether back-related retirements might have been more frequent and differences between the two rehabilitation groups might have been found if older age groups and patients with more severe disability had been included in the study. Haldorsen and coauthors (2002) found that those sick-listed employees with the poorest prognosis for return to work returned to work at higher rate at 14 months after extensive multidisciplinary treatment than after ordinary treatment by a general practitioner (55% and 37%, respectively). However, the results of the present study concerning sick leaves and retirements after rehabilitation are in agreement with the findings of two other Finnish studies (Härkäpää et al. 1990, Mellin et al.1993).

The number of annual visits to doctors because of LBP diminished significantly in the AKSELI and CNT group. Similarly, the annual number of courses of outpatient physical therapy diminished significantly. However, the differences between the groups were statistically nonsignificant. Mayer and coauthors (1987) reported that the frequency of use of health-care services at two years was more than double in a control group compared with a functional restoration group. The difference in findings concerning health-care visits in comparison with the present study may be explained by the fact that the control subjects in the study of Mayer and coauthors (1985a, 1987) received no rehabilitation while the controls in the present study participated in the three-week CNT Programme. Also in the study of Bentsen and coauthors (1997), dynamic strength exercises significantly reduced health-care use by 57-year-old women with CLBP after one year, but not after three years. The results of the present study concerning health-care use nevertheless differ from another Finnish rehabilitation study (Arokoski et al. 2002). In the latter, there was no difference in the use of health-care services by patients with chronic musculoskeletal symptoms in the back and neck between baseline and at 1.5-year follow-up examination after vocationally oriented rehabilitation, although significant beneficial effects were noted in physical performance and pain (Arokoski et al. 2002). The reason for the difference between these two Finnish studies is difficult to explain.

Sick leave, retirement and health-care use belong to the participation component of the ICF framework. It is evident that there will be issues related to work or working environments and compensation involvement (Milhous et al. 1989, Rainville et al. 1997) which may have a stronger effect than improved body functions on participation. High disability predicts also high depressive symptoms (Epping-Jordan et al. 1998), which may interfere with returning to work of some CLBP patients. In the study of Krause and coauthors (2001), 433 people who had received workers' compensation for low back disability were followed up for one to four years. High physical and psychological job demands and low supervisory support were each associated with about 20% lower return-to-work rates during all disability phases. According to Hildebrandt and coauthors (1997), significant determinants of the probability of a patient returning to work after a multidisciplinary rehabilitation programme included the patient's own prediction regarding his/her return to work, the length of absence from work, whether a pension had been applied for or not, and a decrease in disability after rehabilitation. To a lesser degree, factors such as occupational stability, skill discretion at work, coworker support and the responses of the workers' compensation system and employer to the disability may also have value in predicting who will return to work (Schultz et al. 2004).

6.2.6 Dynamic back extension endurance and back-related work disability

In the present study dynamic trunk extensor performance was inversely correlated with the risk of permanent retirement caused by low back disorders but not retirement caused by other diseases. The association remained significant after adjustment for potential confounders and effect-modifying factors. This is an original finding not previously reported in the literature. One other prospective cohort study concerning the risk factors for back-related disability retirement has been published (Hagen et al. 2002). Using questionnaires, the authors found that factors such as "physically demanding work", "poor general health" and "feeling of being worn out" were significantly associated with future back-related disability retirement in Norway. In a comparison of former elite athletes with control subjects, Videman and coauthors (1995) found that while back pain was less common among former athletes than controls, there was no difference between the groups in back-related hospitalisation or retirement. Disability retirement for low back disorders is a complicated issue (Burton et al. 1997), involving contextual factors as set out in the ICF.

In a five-year prospective study, poor back muscle strength was not predictive of future LBP (Kujala et al. 1996). In 152 shipyard workers, isometric trunk extensor strength testing could not predict workplace claims of back injury in a two-year follow-up (Mooney et al. 1996). No isokinetic lifting, psychophysical lifting or static back muscle endurance test was useful as a predictor of future LBP in a study with a 12-month follow-up (Gibbons et al. 1997). An isometric lifting strength test done to 172 industrial workers did not predict the occurrence of industrial back problems during a four-year follow-up (Battié et al. 1989). Isokinetic trunk flexion or extension strength alone was unable to predict LBP during a five-year follow-up, whereas low trunk extensor strength in relation to trunk flexor strength in isokinetic tests on 30 men and 37 women proved to be a risk factor for LBP (Lee et al. 1999). In a cohort of 307 asymptomatic subjects and a cohort of 123 subjects with previous episodes of LBP, in which the occurrence of LBP was monitored for two years, poor isokinetic trunk extension strength predicted future LBP only among the subjects with previous LBP episodes (Takala & Viikari-Juntura 2000). However, in several studies good trunk extensor endurance seems to offer at least some protection against LBP. Biering-Sørensen (1984) found that good isometric endurance of back muscles prevented first-time occurrence of LBP in men but not in women during a 12-month follow-up. Luoto and coauthors divided their subjects into tertiles according to their static back endurance and noticed that the risk of LBP was not linear with respect to back endurance but accumulated in the lowest tertile of muscle performance (Luoto et al. 1995). In a 10-year follow-up study, Leino and coauthors (1987) measured the dynamic trunk muscle flexor and extensor performance (maximum number of repetitions in 30 s) of 902 subjects at baseline. They found that men with poor results in the tests at baseline had a slightly elevated risk of LBP and speculated that trunk muscle fitness may play an aetiological role in the development of LBP. Nygård and coauthors (1991) used the sit-up test (maximum number of repetitions in 30 s) to assess the dynamic trunk muscular endurance of 72 men and 65 women and found that trunk flexor endurance correlated significantly with a work ability index both in healthy subjects and in subjects with diagnosed musculoskeletal disease.

The performance level of the subjects in dynamic fatiguing trunk exercises is associated with diminished co-ordination of trunk movement (Parnianpour et al. 1988) and impaired sensation of changes in the position of the lumbar spine (Taimela et al. 1999). Poor endurance of trunk extensor muscles may lead to increased vulnerability of the spine during dynamic fatiguing loading, which may result in injuries, CLBP and subsequent disability. The results of the present study support the hypothesis that good dynamic trunk extensor performance may protect against work-related disability caused by chronic back disorders. Good co-ordination of lumbar spine movements may call for good trunk muscle endurance, which might explain the protective effect of good dynamic trunk extension endurance against back-related work disability.

6.3 Conclusions

1. Selective type 2 fibre atrophy in lumbar muscles is a common finding in subjects without back disorders, indicating that a sedentary lifestyle does not provide sufficient activation of type 2 fibres for maintenance of normal fibre size in back muscles.

2. The multifidus muscles of CLBP patients show selective atrophy of type 2 fibres, which is comparable that found in sedentary subjects without CLBP. The everyday activity of CLBP patients is sufficient to maintain normal fibre size in the vastus lateralis muscles.

3. Intensive rehabilitation is effective in improving the isokinetic strength of trunk extension in men and increasing the size of type 2 fibres in their multifidus muscles. Women can also improve their trunk extension strength significantly but the size increase of type 2 fibres in their multifidus muscles is statistically nonsignificant. Intensive rehabilitation is effective in increasing knee extension strength and in inducing enlargement of type 2 fibres in the vastus lateralis muscle in both men and women.

4. Isokinetic measurement of trunk strength brings no added value to ordinary clinical evaluation of back function in CLBP patients as compared with simple repetitive tests, although isokinetic devices do provide accurate methodology for trunk strength measurements.

5. An intensive physical and psychosocial training programme is more effective than a less intensive conventional rehabilitation programme in improving body functions and activity in CLBP patients of 30 to 47 years of age. On the other hand, there is no difference between these programmes in outcome variables (sick leave, retirement) belonging to the component of participation in ICF.

6. Good dynamic trunk extension endurance protects against back-related disability in an adult population with mean follow-up period of 12 years.

6.4 Clinical implications

It became apparent in the course of the present study that ordinary clinical practice does not require expensive isokinetic devices while simple, inexpensive nondynamometric tests are still perfectly useful for evaluating back function in patients with CLBP.

The present study indicates that the back muscle impairment is caused more by the inability of CLBP patients to recruit their back muscles effectively than by atrophic changes in their back muscles, as similar selective type 2 muscle fibre atrophy was in people without known back disorders. For improvement of the back strength of CLBP patients, training regimens aimed at restoring the patient's ability to recruit back muscles in more physiological way might suffice. Dosage of exercise is crucial in back rehabilitation. On the basis of the present study, women may need much longer or more intensive training than men, to reach similar rates of hypertrophy in back muscle fibres. The question whether the duration and exercise content of back rehabilitation programmes should be different for men and women, may warrant further study.

A sedentary lifestyle will cause type 2 fibre atrophy in lumbar muscles, even in people without back disorders. The finding that good trunk extensor performance affords some long-term protection against back-related disability retirement suggests that people without current CLBP symptoms might also benefit from good back muscle fitness later on in their working life.

TIIVISTELMÄ

Selkälihakset ja pitkäaikaista selkäkipua sairastavien potilaiden intensiivinen kuntoutus. Vaikutukset selkälihasten rakenteeseen ja toimintaan sekä potilaiden vajaakuntoisuuteen

Tämän tutkimuksen, joka koostui viidestä osatutkimuksesta, tarkoituksena oli tutkia: a) Minkälainen on selkälihasten mikroskooppinen rakenne niillä henkilöillä, joilla ei ole todettu olevan selkäsairautta ja toisaalta henkilöillä, joilla on ollut pitkäaikaisia selkäkipuja? b) Pystyisivätkö pitkäaikaista selkäkipua poteneet henkilöt kasvattamaan selkä- ja alaraajalihastensa lihassyiden kokoa intensiivisellä harjoittelulla? c) Mitä hyötyä on isokineettisestä voimamittauksesta pitkään selkäkipua poteneiden henkilöiden selän toimintakyvyn arvioimisessa? d) Mitä etua on intensiivisestä kuntoutuksesta pitkäaikaisista selkäkivuista kärsivien henkilöiden selän toimintakyvyn ja suorittamisen sekä osallistumisen kannalta verrattuna vähemmän intensiiviseen kuntoutukseen? e) Millainen yhteys on vartalon lihasten kestävyydellä selkäsairaudesta johtuvaan työkyvyttömyyteen pitkällä aikavälillä?

Eri selkälihasten mikroskooppista rakennetta selvittävän tutkimuksen aineisto muodostui 21 äkillisesti kuolleesta henkilöstä, joilla ei sairauskertomustietojen perusteella ollut pitkäaikaisia selkäkipuoireita. Selkäoireiden vuoksi kuntoutukseen lähetetyistä henkilöistä 30 osallistui vapaaehtoisesti selän multifidus ja reiden vastus lateralis lihasten biopsiaan alkututkimuksen yhteydessä ja intensiivisen selkäkuntoutuksen jälkeen kolmen kuukauden seurannassa. Osatutkimukseen, jossa tutkittiin vartalon isokineettisten voimamittausten ja toisaalta tavanomaisten vartalon toistosuoritustestien sekä selän staattisen kestävyystestin yhteyttä selkäkipupotilaiden toimintakykyindeksiin, osallistui 185 potilasta. Kontrolloituun hoitotutkimukseen, jossa intensiivistä kuntoutusohjelmaa verrattiin vähemmän intensiiviseen kuntoutusohjemaan, osallistui yhteensä 378 potilasta (ikä 30—47 vuotta). Molempien kuntoutusohjelmien toteutumisen jälkeen selän toimintakyky ja henkilöiden suorittaminen sekä osallistuminen mitattiin kolmen ja 12 kuukauden seurannoissa. Kohorttitutkimuksessa, jonka aineisto muodostui 535 henkilöstä, mitattiin aluksi selkä ja vatsalihasten kestävyys ja sen jälkeen toteutettiin seuranta (keskiarvo 12 vuotta) eläketapahtumien suhteen osallistujien eläkkeelle siirtymiseen tai kuolemaan tai seuranta-ajan loppumiseen asti.

Äkillisesti kuolleiden henkilöiden lihasnäytteiden analyysissä tyyppi 1 (hitaasti supistuva) ja tyyppi 2 (nopeasti supistuva) syiden lukumääräiset osuudet tai niiden koko ei vaihdellut merkitsevästi multifidus tai iliocostalis lihasten välillä eikä multifiduksessa eri näytteenottotasojen välillä. Jopa niiden henkilöiden selkälihaksissa, joiden kohdalla sairauskertomustiedoissa ei ollut merkintöjä selkäoireista, voitiin todeta tyyppi 2 syiden surkastumista. Pitkäaikaisista selkäkivuista kärsineiden miesten ja naisten osalta tyypillinen multifiduksen mikroskooppisen rakenteen löydös oli se, että tyyppiä 1 olevat syyt olivat säilyneet kookkaina, mutta tyyppiä 2 olevat syyt olivat surkastuneet. Sen sijaan sel-

käpotilaiden reisilihaksissa molemmat syytyypit olivat normaalin kokoisia. Intensiivinen kuntoutusohjelma pystyi kasvattamaan merkitsevästi tyyppiä 2 olevia lihassyitä miehillä sekä multifidus, että vastus lateralis lihaksissa. Naisten suhteen ainoastaan vastus lateraliksessa voitiin todeta tyyppi 2 syiden koon merkitsevä kasvu kuntoutuksen jälkeen. Vatsalihasten ja selkälihasten toistosuoritustestit olivat parantuneet merkitsevästi enemmän intensiivisen kuntoutuksen kuin vähemmän intensiivisen kuntoutuksen ryhmässä kolmen kuukauden seurannassa. Ero ryhmien välillä oli merkitsevä miesten suhteen vielä 12 kuukauden seurannassakin, mutta naisten osalta ero säilyi vain vatsan toistosuoritustestin kohdalla. Vuoden kuluttua intensiivisemmässä kuntoutuksessa olleilla oli yhä edelleen vähemmän selkäkipuja ja vähemmän toimintakyvyn rajoittumista kuin kevyemmässä kuntoutuksessa käyneillä. Kuitenkaan mitään merkitsevää eroa erilaisen kuntoutuksen saaneiden välillä ei voitu havaita sairauslomien ja eläkkeelle jäämisen suhteen. Kun isokineettisiä vartalon suorituskykymittauksia verrattiin tavanomaisiin toistotesteihin, niin voitiin todeta, että etenkin selkäkipuja pitkään kärsineiden miesten kohdalla isokineettiset tulokset korreloivat huonommin selkäkipupotilaiden toimintakykyindeksiin kuin vartalon yksinkertaiset toistotestit.

Multifidus edustaa hyvin alaselän lihasten mikroskooppista rakennetta, koska mikroskooppisen rakenteen vaihtelu oli vähäistä eri alaselän lihasten ja myös eri näytteenottotasojen välillä. Äkillisesti kuolleiden henkilöiden selkälihasten mikroskooppisen rakenteen löydösten perusteella voidaan päätellä, että nykyaikainen, vähän liikuntaa ja selän kuormittamista sisältävä elämäntyyli ei näytä aktivoivan riittävästi tyyppiä 2 olevia selkälihasten syitä edes selän suhteen oireettomilla tai vähäoireisilla henkilöillä ja aktivoinnin puutteessa kyseiset syyt surkastuvat. Tyyppiä 1 olevat syyt selkälihaksissa ovat säilyttäneet kokonsa, koska niiden aktivoitumista tapahtuu jatkuvasti asentoa ylläpitävissä selkälihasten tehtävissä. Intensiivinen kuntoutus pystyi parantamaan sekä miesten että naisten isokineettistä selän ojennusvoimaa. Miesten kohdalla voiman paraneminen voidaan selittää mahdollisten keskushermostollisten tekijöiden ja neuraalisen adaptaation muutosten lisäksi tyyppiä 2 olevien syiden koon kasvulla selkälihaksissa. Naisten osalta voiman lisääntymistä selittävät ainoastaan kaksi ensin mainittua tekijää. Jos yhtenä kuntoutuksen tavoitteena on parantaa selkälihasten rakenteellisia ominaisuuksia lisäämällä myös tyyppiä 2 olevien syiden kokoa, naiset tarvitsisivat pidempiaikaisempaa tai vieläkin intensiivisempää harjoittelua. Intensiivistä fyysistä ja psykososiaalista harjoittelua sisältänyt kuntoutusohjelma osoittautui tehokkaammaksi kuin kevyempi kuntoutusohjelma selän toimintakyvyn kohentamisen ja selkäkipupotilaiden aktiivisuuden suhteen, mutta vuoden kuluttua ohjelmat eivät eronneet sairauslomien tai eläkkeelle siirtymisten suhteen. Aikuisväestölle tehdyn kohorttitutkimuksen perusteella voidaan päätellä, että selkälihasten hyvä dynaaminen kestävyys voi estää ennenaikaista selkäsairaudesta johtuvaa eläkkeelle joutumista. Isokineettisestä vartalon voimamittausmenetelmästä ei löytynyt sellaisia mittareita, jotka olisivat käyttökelpoisempia kuin yksinkertaiset vartalon toistosuoritustestit selkäkipupotilaiden selän suorituskyvyn kliinisessä arvioimisessa.

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APPENDICES

APPENDIX 1 The Million pain and disability index in the present study was derived as mean score of 14 questions. Question 1 demonstrates the visual analogue scale (a line of 100mm) used for all questions. The range of the scale was 0 to 100 (0=no pain or disability, 100=the worst possible pain or disability).

1 Do you have any pain in the back? How severe is it?
No pain ____ intolerable

2 Do you have any pain in the night? How severe is it?
3 Do you get relief from pain killers?
4 Do you have any stiffness in the back?
5 Does your back pain interfere with your freedom to walk?
6 Do you have discomfort when walking?
7 Does your pain interfere with your ability to stand still?
8 Does your pain prevent you from turning and twisting?
9 Does your back pain allow you to sit on an upright hard chair?
10 Does your back pain prevent you from sitting in a soft armchair?
11 Do you have back pain when lying down in bed?
12 What is your overall handicap in your complete lifestyle because of back pain?
13 To what extent does your pain interfere with your work?
14 To what extent does your work have to be modified so that you are able to do your job?

APPENDIX 2 Leisure-time physical activities were divided into (A) physical exercises for treatment of back disorders, (B) fitness training and (C) other physical activities. Each of these classes of physical activity (A, B, C) was quantified by multiplying the points for frequency (A1, B1, C1) by the points for duration or intensity (A2, B2, C2). The strenuousness index (scale 0—10) for the leisure-time physical activities of the subject was calculated dividing the sum [(A1xA2) + (B1xB2) + (C1xC2)] of the different activities by 4.

A1 How often do you exercise to treat your back disorder?
0 = not at all
1 = once a week or less often
2 = a few times a week
3 = once a day
4 = more frequently than once a day

A2 What is the usual duration of your exercise session?
0 = no exercises
1 = less than 5 minutes
2 = 5—14 minutes
3 = 15—30 minutes
4 = more than 30 minutes

B1 How often do you undertake fitness training?
0 = not at all
1 = less than once a week
2 = once a week
3 = twice a week
4 = three times a week or more frequently

B2 Which one of the following best describes the intensity of your fitness training?
0 = no fitness training at all
1 = my fitness training usually involves no sweating or breathlessness
2 = my fitness training is usually of moderate intensity with some sweating and breathlessness
3 = my fitness training is usually of high intensity with considerable sweating and breathlessness

C1 How often do you undertake activities like gardening, cleaning and home repairs in your leisure-time?
0 = not at all
1 = less than once a week
2 = once a week
3 = twice a week
4 = three times a week or more frequently

C2 Which one of the following describes the intensity of your above-mentioned activities?
0 = I have no such activities
1 = these activities usually involve no sweating or breathlessness
2 = these activities are of moderate intensity with some sweating and breathlessness
3 = these activities are usually of high intensity with much sweating and breathlessness

APPENDIX 3 AKSELI Programme in Study IV.

The programme included 37 h of guided or self-controlled physical exercises and 5 h of group discussions per week. Individual consultation on problems at work was available if needed. Passive physiotherapy was not given. The programme was carried out by a team consisting of a doctor, a psychologist, a social worker, a physiotherapist, an occupational therapist and a work training supervisor.

The programme consisted of the following:

1) For training of the trunk and limbs, 1RM was determined for each subject. The resistance training programme involved the following loads and numbers of repetitions:
   a) twice a week, one to three repetitions per set at 90—100% of 1RM, one set per session.
   b) three times a week, eight repetitions per set at 80% of 1RM, two or three sets per session.
   c) twice a week, 12 repetitions per set at 60% of 1RM, two or three sets per session.
2) Cardiovascular endurance exercises were done daily, including indoor and outdoor games, hiking, clay working and work simulation tasks.
3) Guided relaxation and several rest periods were included between physical exercises.
4) Stretching was carried out both before and after other exercises.
5) Cognitive-behavioural disability management groups (relaxation, visual images, problem-focused discussions, homework) encouraged the patients to deal with life stress by new decision-making. Reconceptualising pain and life problems, reprocessing appraisals, attitudes, beliefs and emotions and problem solving were emphasised.