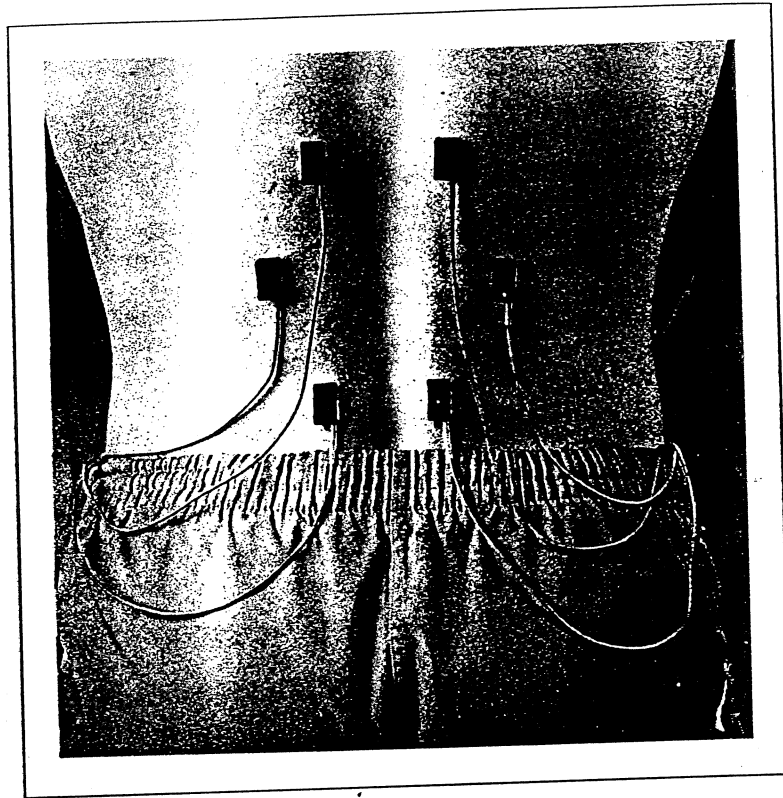# Chapter Seven
Muscle

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Introduction

The most common diagnosis reported for low back disorders is ac
or chronic lumbosacral strain or sprain. This diagnostic terminolc
explicitly suggests that injury to the lumbar musculature is responsi.
for symptoms, yet there is no evidence to support this assertion. T
organization of this chapter, therefore, is designed to present the cl
ical tests currently, available for assessing lumbar muscle functic
Because the clinical syndromes possibly associated with injuries
other disorders of muscles remain speculative, this material appe;
in Part B of this chapter; conversely, the anatomy of the spinal mi
culature is included in Part A because it forms the basis for und‹
standing the functional tests described. Also, some clinical symptoɪ
(such as postural disturbances) and syndromes (such as fibromyalȷ
and lumbar compartment syndrome) that involve both fascial strʟ
tures and muscle appear in Chapter 6:

The Anatomy of the Lumbar Back Muscles

A lumbar back muscle can be defined as any muscle lying in t;
posterior compartment of the spine that can exert a force on the lumb
vertebrae. This definition encompasses those muscles that attach
the lumbar vertebrae and those that cross the lumbar vertebrae b
lack any attachment to them. Morphologically, the lumbar back mu
cles can be divided into short (intersegmental) muscles and loɪ
(polysegmental) muscles.

The intersegmental muscles are the interspinales and intertransvɛ
sarii. Although present at every lumbar intervertebral joint, these mu
cles are small.

There are only two polysegmental muscles of the lumbar spine, tl
multifidus and the erector spinae. The lumbar multifidus is the mo
medial of the lumbar back muscles and anatomic studies have shoᴡ
that it consists of five segmental bands. Each stems from a spinoɪ
process and consists of several individual fascicles with various caud,
insertions.[1,2] The shortest fascicle in each band arises from the caud;
edge of the spinous process and spans two intervertebral joints. Lor
fascicles arise from a common tendon from the tip of the spinoɪ
process and span three to five segments. The fascicles are inserte
systematically into the mamillary processes of the lumbar vertebra·
the posterior superior iliac spine, and the dorsal surface of the sacruɪ
and posterior sacroiliac ligament. Dissections have shown that all fa;
cicles arising from a given spinous process are innervated by a singȷ
nerve, the medial branch of the dorsal ramus with the same segment;
number as the spinous process.[1]

Traditionally, the erector spinae in the lumbar region has been d‹
scribed as having three parts: the longissimus thoracis, the iliocostalȷ
lumborum, and the spinalis thoracis (or spinalis dorsi). The spinalȷ
thoracis is principally a muscle of the thoracic region. It is relativeɪ
small and only its lowest fibers enter the lumbar region to insert int·

the L1 to L3 lumbar spinous processes. Consequently, it has little role to play in lumbar spinal movements. The longissimus thoracis and iliocostalis lumborum, however, are massive muscles with substantial actions on the lumbar spine. Topographically, the iliocostalis lumborum lies lateral to the longissimus thoracis and forms the lateral border of the erector spinae in the lumbar region. The longissimus thoracis lies adjacent to the multifidus, separated from it by a distinct, vessel-filled cleavage plane. In the lumbar region, the longissimus thoracis and iliocostalis lumborum appear to form a single common muscle mass but dissection reveals that the two are separated by a parasagittal aponeurosis, the lumbar intermuscular aponeurosis, with the longissimus lying medial to this aponeurosis and the iliocostalis lateral to it.[3] In the thoracic region, the muscles diverge and are separated distinctly by the iliocostalis thoracis.

Dissections have shown that the longissimus thoracis and iliocostalis lumborum each consist of thoracic and lumbar fibers and may be described as having four parts: the longissimus thoracis pars thoracis, the iliocostalis lumborum pars thoracis, the longissimus thoracis pars lumborum, and the ilicostalis lumborum pars lumborum.[3] The thoracic fibers arise from thoracic transverse processes or ribs, whereas the lumbar fibers arise directly from lumbar vertebrae.

The longissimus thoracis pars thoracis consists of multiple independent fascicles that arise from the transverse processes and ribs of the T1 and T12 segments by way of narrow, flattened tendons. Each tendon forms a short, small muscle belly that then forms a long caudal tendon. These tendons are inserted serially into the lumbar and sacral spinous processes, the back of the sacrum, and the posterior superior iliac spine. Over the lumbar region, the side-to-side aggregation of these caudal tendons forms approximately the medial half of the erector spinae aponeurosis.

The iliocostalis lumborum pars thoracis consists of eight fascicles that arise from the tubercles of the lower eight ribs. Each fascicle consists of a small muscle belly that gives rise to a longer caudal tendon. These tendons form the lateral part of the erector spinae aponeurosis and insert into the iliac crest.

The longissimus thoracis pars lumborum consists of five fascicles that arise, one from each segmental level, from the accessory process of a lumbar vertebra and the adjacent medial four fifths of the transverse process. Caudally, the fascicles become aponeurotic and blend to form the lumbar intermuscular aponeurosis, which ultimately inserts into a concentrated area on the medial aspect of the posterior superior iliac spine.

The iliocostalis lumborum pars lumborum consists of four fascicles that arise, one from each segmental level, from the tips of the L1 to L4 transverse processes and the adjacent posterior surfaces of the middle layer of the thoracolumbar fascia. Caudally, each fascicle inserts directly into the medial end of the iliac crest, lateral to the posterior superior iliac spine.

Recent studies of the lumbar erector spinae reveal that it consists

of four separate, recognizable parts and that only the thoracic fibers of the longissimus thoracis and iliocostalis lumborum contribute to the erector spinae aponeurosis. The lumbar fibers that form the bulk of the erector spinae in the lumbar region arise from individual lumbar vertebrae and insert into the iliac crest and remain independent of the erector spinae aponeurosis.

Measurement of Trunk Muscle Function by Myoelectric Activity

The dual function of the trunk muscles is to maintain the stability of the vertebral column and to control intervertebral spinal motions. The activities of different trunk muscles cannot be measured directly in mechanical quantities; they can only be estimated indirectly by means of electromyography. However, the analysis of myoelectric activity has been used as one of the major clinical methods for understanding the function of muscles in the spine.[4]

Studies of the myoelectric activity found in different trunk muscles or groups of trunk muscles have been performed while positions were held statically and moved through dynamically. External loads have been applied by weight applications to the trunk or the arms or by preventing the trunk from moving in different directions. Failure to distinguish between the specific loading conditions has sometimes produced apparently conflicting results when in actuality the results were not strictly comparable because they were obtained under different conditions.

Studies of the myoelectric activity of the lumbar erectores spinae and the torque generated by these muscles have demonstrated that the relationship between myoelectric activity and force output is not linear over the entire force range of a muscle. Synergistic and antagonistic muscle activities can complicate these relationships, as can different muscle characteristics and individual variations among subjects. Stokes and associates[5] explored the relationship between the myoelectric activity of the trunk extensor and torque, and concluded that the most repeatable relationship was obtained by fitting a linear regression to the relationship. In individual subjects, however, the relationship was nonlinear. The myoelectric activity-torque relationship of abdominal muscles in isometric flexion has also been studied. In one recent such study, a quadratic regression was found that described the relationship better than did a linear one (I.A.F. Stokes and associates, unpublished data). However, under conditions of developing axial torques, some abdominal muscles have a linear torque-myoelectric activity relationship, whereas others do not. Thus, these relationships of myoelectric activity and torque vary from muscle to muscle, and are influenced by the specific loading conditions.

Myoelectric Activity and Posture

Although the word posture can apply to any defined static position, it normally refers to standing, sitting, and lying.[6,7] The myoelectric

activity of the trunk muscles in erect standing and in sitting postures has been studied extensively. Much of this work has been summarized previously and will not be repeated here.[8-10]

Standing For standing postures controversy exists as to whether or not the paraspinal muscles are active or relaxed. Most studies indicate slight myoelectric activity, usually less in the lumbar and cervical regions than in the thoracic region.[8,9,11-22] Asmussen and Klausen[23] found slight activity in erect standing posture in either the paraspinal muscles or the abdominal muscles, but not in both. The evidence today suggests that the paraspinal muscles are active in upright standing but that the level of activity is low and that there are considerable variations among test subjects. Concomitant with activities in the paraspinal muscles, there is slight activity in the vertebral portion of the psoas major muscle.[8,13,24-26]

Studies of the abdominal muscles have been confined to the rectus abdominis and the external and internal oblique muscles. No conclusive information is available about the transversus abdominis muscle. These studies reveal that the abdominal muscles are slightly active during relaxed standing, particularly the internal oblique muscles.[27-31]

Sitting Although the activity of the paraspinal muscles in the lumbar region is similar in standing and in unsupported sitting, there is a somewhat higher level of activity in the thoracic region during sitting.[8,9,14,20,28,32-34] Some information is also available on abdominal muscle activity in sitting. Carlsöö[14] recorded slight activity in the anterior oblique muscles, but the rectus abdominis and transverse muscles were not investigated. These results agreed with those of Schultz and Andersson,[35] who studied several supported sitting postures. They found slight activity in the rectus and oblique abdominal muscles, as long as the posture was sagittally symmetric. The iliopsoas muscle is also slightly active when a sitting posture is assumed.[8,24,25]

Andersson[32,36] summarized several studies of supported sitting and of work activities in sitting postures. The myoelectric activity of the trunk muscles is influenced by the posture of the seated subject, by supports on the chair, and by the specific work activities performed. Levels of activity are quite low in all trunk muscles when the trunk is adequately supported. A study by Hosea and associates[10] supported the findings of Andersson and associates[8] that backrests and lumbar supports both contribute to a lower level of activity in lumbar back muscles.

In an attempt to define optimal seat support, Bendix and associates[37] studied the myoelectric activity of lumbar muscle levels when the subject sat in a chair with a posteriorly inclined seat, an anteriorly inclined seat, and a tiltable seat. There was no difference in activity. Myoelectric activities during office work and model calculations of trunk forces suggest that, in general, they are quite low and marginally influenced by table and chair adjustments.[36]

Effects of Sudden Load on Postural Control

Carlson and associates[38] investigated postural control in situations in which the body was subjected to sudden, unexpected loads in the sagittal and frontal planes. The latency of muscle activation compensating for the perturbed load was 61 to 91 m/sec. The vestibular system and receptors in the trunk and limbs were assumed to be involved, since experiments with unblindfolded and blindfolded subjects revealed no differences. Given the absence of irregularity of back muscle activation under load perturbation in the coronal plane, they concluded that the back muscles play a minor role in compensating for side perturbations.

Marras and associates[39] measured the activities of six back muscles when weights were dropped into a box that the subjects held in front of them. The weight drop was expected or unexpected (in this case the subjects were blindfolded and wore earplugs). The muscle activities under conditions of unexpected load were higher than those when the subject anticipated the load. The increase was quite substantial; the calculated muscle forces were, on the average, 70% higher.

Myoelectric Activity During Forward Flexion

Forward flexion of the trunk is a combined movement of the spine and pelvis. The first 50 to 60 degrees are accomplished by motion of the lumbar spine and additional flexion primarily by rotation of the pelvis.[40,41] In extension, the reverse applies; first the pelvis rotates backward, after which extension of the lumbar spine completes the movement.

The muscles of the trunk control this pattern of motion elegantly, as indicated by their myoelectric activity. During the first portion of a flexion movement, strong activity is found in the gluteus maximus, the gluteus medius, and the hamstring muscles[42,43]; this locks the pelvis and prevents motion at the hip joints. As flexion progresses, the increasing trunk moment is balanced by a corresponding increase in back muscle activity. In the fully flexed position, however, the activity ceases almost completely.[8,9,12,17,19,24,42–53] Floyd and Silver[47] hypothesized that the so-called flexion-relaxation phenomenon of the back muscles results from reflex inhibition, but other explanations are also possible.

The most popular is that in the fully flexed posture the trunk moment is resisted by structures other than muscles. Most investigators have concluded that the ligaments and other structures (fascia, facet joints) provide the major share, together with stretched extensor muscles. The evidence supporting what is now termed the flexion-relaxation phenomenon or "flexion silence" is incomplete. The main reason for the interest in the flexion-relaxation phenomenon is the desire to understand problems that may be caused by lifting and other work activities in flexed postures. Kippers and Parker[54] determined the relationship between degree of flexion and decrease in myoelectric activity, and also discussed a variety of possible explanations for the phenomenon. Schultz and associates[55] calculated the tissue tensions involved in the

flexion-relaxation phenomenon. They also determined that the back muscles are electrically quite active during exertion in the same postures in which flexion-silence is observed without exertion. Farfan and Lamy,[56] using a mechanical model, found stress on the ligaments to be considerable and close to their failure strength. Gracovetsky and associates[57,58] implicated the thoracolumbar fascia, as well as spinal ligaments in these situation. Adams and associates[59] examined the role of the lumbar intervertebral joints, and reached no certain conclusions. In the control of pelvic stability through the flexion movement, the gluteus maximus relaxes as full flexion is approached; the hamstring muscles are greatly active at first and remain active throughout the flexion movement.

In contrast to the extensor muscles, the abdominal muscles are active only during the first few degrees of flexion, that is, when the movement is initiated.[6,12,28,30] Thereafter, gravitational forces alone apparently cause the movement under conditions in which there are no applied external loads.

Other studies of static positions of flexion have found an increase in the myoelectric activity of the back muscles, both when the angle of flexion was increased and when external loading was increased at a fixed angle of flexion.[35,43,50,60] In attempted flexion resisted by external forces, on the other hand, the abdominal muscles are strongly active while there are only low levels of activity in the lumbar part of the erector spinae muscle.[61-65]

Myoelectric Activity During Extension

When the trunk rises again from the flexed to the upright position, the sequence is the reverse of that when bending forward.[12,17,19,24,28,43,46,66] The gluteus maximus comes into action early, which is interpreted to mean that muscle initiates extension together with hamstrings.[43] The paraspinal muscles become active somewhat later, indicating that the extension movement starts with fixation and posterior rotation of the pelvis produced by the gluteus maximus.

It is noteworthy that extensor muscle activity is greater when the trunk is being raised than when it is being lowered, although in neither is it close to its maximum.[17,43,67] The direction of the movement in relation to the weight forces of body segments is obviously important. This has been shown in studies of other body segments raised or moved horizontally.[68-70] Moreover, changes of the lumbar curvature influence the activity. For example, in postures of forced lumbar lordosis the myoelectric activity of the back muscles is increased.[43,44]

When the trunk is extended from the upright position, myoelectric back muscle activity appears fairly early during the initial phase, but after the gluteus maximus has become active. The muscles are also active in the position of full extension.[12,16,19,24,52] Between these two extremes of movement, there is only slight activity. The abdominal muscles, particularly the rectus abdominis, however, show increasing activity throughout the extension movement.[12,28] Extension of the trunk

against resistance results in a marked increase in the activity of the muscles of the lumbar region of the back.[19,52,61,64,65]

Myoelectric Activity During Lateral Flexion and Twisting

When the trunk is flexed laterally, the myoelectric activity increases in the posterior back muscles on both sides of the spine. The main increase in activity in the lumbar region is on the side contralateral to the direction of lateral bend.[17,20,24,42,66] When the trunk is loaded by the arm in lateral flexion, comparatively higher levels of activity are found on the contralateral side of the lumbar region while in the thoracic region the increase in activity is found on the ipsilateral side.[60] In the lumbar region, the activity is higher when the surface electrodes are placed farther from the midline, that is over more laterally placed muscles. This increased activity can be predicted from model calculations as well as from intramuscular electrode studies by Jonsson.[61] He found the iliocostalis and longissimus muscles to be active in lateral flexion, whereas the multifidi muscles, which are closer to the spine, were usually inactive. The response of the back muscles to a loading condition in which a weight is held in one hand during upright posture is equivalent to that in lateral flexion: the contralateral muscles contract.[24,60]

The abdominal muscles also show activity in lateral flexion both ipsilaterally and contralaterally, with the level of activity higher on the contralateral side. Carlsöö[42] recorded strong activity in the gluteus medius and the tensor fasciae latae muscles on the ipsilateral side. This reflects the force necessary to rotate the pelvis and the trunk.

Raftopoulos and associates studied whether the flexion-silence phenomenon of back muscles exists in lateral flexion as well (unpublished data). A relaxation phenomenon does seem to occur in the laterally bent trunk posture, but only in the erector spinae. The oblique abdominal muscles remain active.

Pope and associates[71,72] studied the myoelectric activity of trunk muscles when twisting was attempted, both with and without prerotation of the trunk. In general, they found a linear relationship between force output and myoelectric activity. However, high levels of antagonistic activity were found in both abdominal and posterior back muscles. In some muscles, prerotation increased the antagonistic activity. In both these experiments, the highest activity levels were found in the erector spinae and external oblique abdominal muscles.

Myoelectric Activity During Lifting

The back muscles, the muscles of the buttocks, and the ischiocrural muscles are all myoelectrically active during a lift. The abdominal muscles are also active, but to a lesser degree. The levels of activity in these various muscles are directly related to the trunk moment and are, therefore, influenced by the weight lifted, the body posture, and the location of the mass center of the weight.[12,24,39,43-46,49,50,73-83] The question of whether the spine should be flexed or straight during the

lift has also been studied. Generally, in these studies, activity of the back muscles is similar in a leg lift (spine held straight) and a back lift (spine flexed) or, sometimes, is greater in the back lift.[43–45,49,50,73,84]

Seroussi and Pope[85] investigated the relationship between the myoelectric activity of the trunk muscles and lifting moments in the sagittal and frontal planes. They obtained a linear correlation for the sum of the myoelectric activity of the erector spinae versus the sagittal moment. A corresponding relationship was found in the difference between the myoelectric activity of the erector spinae and the frontal plane moment. This shows that an alteration in the timing and the sequence of muscle recruitment can cause moments in unintended planes.

Myoelectric Activity During Physical Exercise

Studies performed to analyze different strengthening exercises commonly employed in rehabilitation have shown that for the deep back muscles the highest levels of activity occur when the back is arched with the subject in the prone posture.[43,52,86] For the abdominal muscles, the highest activities were recorded in the "V-sit, basket hand, sidelying trunk raise, backward leaning, and curl-up" positions.[31,87]

Myoelectric Activity in Patients With Low Back Pain

One area of interest in clinical research is the relationship between low back pain and the electromyographic activity of muscles.

As early as 1952, Golding[48] reported myoelectric measurements in a series of patients with low back pain. Of 120 patients, 34 did not achieve the expected relaxation of the back muscles during complete flexion of the trunk. These findings were confirmed by Floyd and Silver[24] and Yashimoto and associates,[88] who found that 84 of 104 patients had erector spinae activity that differed from normal activity, primarily in the absence of the flexion-relaxation phenomenon. Wolf and Basmajian[89] studied nine patients in various postures and during functional motions. Muscle activity was lower than, or the same as, that in a healthy control population. Wolf and associates[90] later collected data from 121 men and women without low back pain during dynamic and static conditions to provide a baseline for comparison with patients with low back pain.

Nouwen and associates[91] studied 20 patients with low back pain and 20 pain-free controls during flexion, extension, lateral bending, and rotation. Patients and controls had different myoelectric patterns in that patients with low back pain showed higher paraspinal and lower abdominal activity near full flexion, and less paraspinal activity when returning to the upright standing position. No difference was noted between left-sided and right-sided myoelectric patterns when patients and controls were compared, nor was there a significant difference in rotation or lateral bending. Triano and Schultz[92] studied the flexion-relaxation phenomenon in patients and controls and related those findings to disability rating scales. Almost 50% of the patients did not

exhibit flexion-relaxation, whereas all the controls did. These investigators also found a positive relationship between degree of disability and loss of the flexion-relaxation phenomenon.

Other studies have attempted to determine electromyographically whether or not patients with low back pain have increased muscle activity. Roland[93] pointed out a number of general problems associated with such studies. The patient populations were poorly described, and the role of muscle spasm (or muscle contractions) in the patients with low back pain remained obscure. Also, technical difficulties existed, including positioning of the subjects and recording from selected muscles. In some studies patients with palpable abnormalities in their back muscles had increased myoelectric activity in those areas.[94-98] Kraft and associates,[99] however, found no increase in muscle activity in areas of muscle spasm. Studies of back muscle fatigue will be discussed later.

Measurement of Intramuscular Pressure

Another measure of muscle function is intramuscular pressure. Intramuscular pressure is a good estimator of muscle force under isometric[100,101] and dynamic conditions.[102-104] Passive tension of a muscle increases the pressure at rest.[105] Styf[106] used a microcapillary infusion technique to record intramuscular pressures in the erector spinae muscles. Pressure increased from a resting pressure of 8 mm Hg to as much as 265 mm Hg during contraction. Pressure during sitting increased compared with standing, although there was considerable individual variation. Flexion of the trunk and lifting also increased pressures.

Muscle Strength

Trunk muscle strength has been studied extensively as a means of understanding the function of spinal muscles.

Definitions and General Considerations

In a general sense, muscle strength is defined as the capacity of a muscle to produce the tension necessary for maintaining a posture or initiating or controlling movement during conditions of loading on the musculoskeletal system. At isolated joints, muscle strength can be defined as the ability of a muscle or muscle group to produce a moment of force about a joint.[107]

Terms relevant to the performance of muscle are work, power, and energy. Work is force times distance and is measured in Newton-meters. Power is work times velocity and is measured in watts (Newton-meters per second). Average power is the term used to describe the total amount of work done in a given time divided by the time. Mechanical energy can be stored (potential energy) or released (kinetic energy). Mechanical energy, like work, is measured in Newton-meters.

Types of Muscle Contraction

There are several different types of muscle contraction with definitions that are not completely accepted. All have in common that they require activation of the muscle. The activation is termed muscle contraction, and results in tension within the muscle.

Isometric Contraction   An isometric contraction is one in which there is no change in muscle length during the contraction. In reality, no contraction is completely isometric because, on a fibrillar level, the contracting components of muscle always shorten. The term is currently used to describe contractions in which the external length of the muscle remains unchanged, that is, the muscle contracts but there is little or no shortening. Another definition of an isometric contraction is a contraction in which the external resistance is equal to the internal force developed by the muscle and no external movement is generated. Isometric is often considered to be synonymous with static. Because nothing moves, no work is done and power cannot be generated.

Isotonic Contraction   An isotonic contraction is one in which constant internal force is produced and the muscle shortens. This type of contraction is also called a concentric or shortening contraction. It can also be defined as a dynamic exercise with a constant load or resistance. In reality, pure isotonic contractions are rare, as resistance usually changes. In an exercise with a set weight, for example, the moment arm changes as the joint moves, thus changing the resistance. During an isotonic contraction positive work is produced by the muscle.

A muscle can develop greater tension in an isometric contraction than in an isotonic contraction because energy is not expended to shorten the muscle. As a rule of thumb, the maximum isotonic contraction is about 80% of the maximum isometric tension.

Eccentric Contraction   An eccentric contraction is one in which the external force is greater than the internal force of the muscle. As a consequence, the muscle lengthens while continuing to maintain tension. The term lengthening contraction is sometimes used instead of eccentric. In eccentric contractions, the muscle acts to control the movement, not to initiate it. In this situation the muscle can sustain greater tension that it can develop in isometric contractions at any given static length. The work performed by the muscle during an eccentric contraction is often defined as negative work.

Isokinetic Contraction   Another type of contraction called isokinetic has in recent years become a popular method of measuring strength and providing exercise. The term means "constant force" and in general is used to describe an activity in which an exercise is performed through the range of motion of a joint at a constant velocity. It is a dynamic exercise with resistance in which the speed of motion is controlled. The equipment used to measure isokinetic contractions accommodates the exerted force so that the specified velocity is maintained. Because velocity does not change, the kinetic energy remains constant.

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Although isometric, isotonic, and eccentric contractions are involved in daily human activities, isokinetic contractions do not exist in reality.

Isoinertial Contraction Isoinertial contractions are yet another type of contraction that has attracted considerable recent attention. In this contraction mode, the muscle contracts against a constant load. If the torque generated by the muscle is larger than the resistance (load), the length of the muscle changes and the additional torque accelerates the body segment.

In recent years there have been more investigations of isolated functions of the abdominal and back extensor muscles, but there is still a considerable lack of basic knowledge in this area. This deficiency exists, in part, because the assessment of strength deficits in trunk muscles presents a particular problem. Extremity deficits are more easily quantitated by simple visual observation of atrophy, by muscle circumference measures, and by comparison of the deficient extremity with the normal contralateral side. For this reason, sports medicine programs have focused on the restoration of strength and endurance in the paraarticular musculature as a natural part of any rehabilitation process. In the spine, the absence of visual feedback and a normal side for comparison have made such comparisons more difficult. Although certain neuromuscular conditions (polio, muscular dystrophy, spinal cord injury) have been recognized as causing lumbar dysfunction through muscle wasting, clinicians usually identify atrophy only when a spinal deformity is associated with gross, asymmetric loss of muscle bulk. More subtle forms of trunk muscle atrophy are generally not recognized and, therefore, are not taken into consideration. More research has been done on the relationship between low back and trunk muscle strength[108-111] than that between range of motion and low back pain, but most clinicians pay more attention to motion deficits. These motion deficits, which can be partially visualized, are taken as a more accurate reflection of lumbar spinal dysfunction. The development of mechanical devices to supplement this approach to strength assessment offers a way to overcome this problem.

Measurement of Strength in Normal Subjects

Mechanical measures of force and torque (moment of force) produced by the abdominal and back extensor muscles have been investigated in normal subjects of both sexes. Static and dynamic muscle strength has been the focus of most studies.[108,109,112-122] Strength values for lateral and axial rotation have also been reported.[123] These results can be summarized as follows:

Men as a group are stronger than women but when strength is normalized to body weight women may be as strong as men.[110,117,124] The eccentric (lengthening) dynamic and isometric contractions produce higher levels of strength than concentric (shortening) contractions.[115] As expected, the trunk extensors are stronger than the flexors. When a ratio is used to express the relationship of these two muscle groups,

factors such as type of muscle contraction, trunk angular velocity, and spatial orientation of the trunk must be specified (Thorstensson and Nilsson[118] and Smith and associates, unpublished data). It appears that the trunk extensors are the strongest muscle group in the body. In studies by Smidt and associates,[125,126] the average moment of force generated for eccentric extensor muscle contractions was in excess of 400 N·m. Additional studies have revealed that trunk extensor strength in postmenopausal women is more than double the strength of the knee extensors.[125,126] However, trunk strength seems to diminish noticeably with age, beginning at 40 to 50 years.[127] The endurance of trunk muscles in women is superior to that in men.[117]

Measurements of Strength in Patients

Structural and functional changes occur in muscle after injury. Structural change is most dominant in the early stages. Healing of the structural defect almost invariably occurs in a comparatively short time (albeit with replacement of original tissue by suboptimal scar in severe cases). By contrast, functional deficits are rarely a major factor in human performance in the early posttraumatic stages, but gradually increase, presumably as a result of inactivity and disuse. As time progresses, functional deficits become the dominant physical impairment associated with disability in the patient with chronic back problems. In addition, strength testing during the early posttraumatic period is rarely useful and the results are often invalid because of pain. There is some evidence that overaggressive attempts to measure performance may actually exacerbate the injury. Given the known characteristics of soft-tissue healing, these concerns should no longer apply three to six weeks after the onset of symptoms. From the natural history of low back pain, it can be anticipated that about 80% of acute cases will resolve spontaneously within six weeks.

Comparisons of patients with low back pain with normal subjects have used peak-strength measures for isometric and concentric contractions.[111,114,115,117,120,123,125-137] The patients were not weaker in all the studies, and the variation among patients tends to be higher than among normal subjects during tests of consecutive intermittent contraction. The strength decrement (initial effort versus final effort, a measurement of muscle fatigue) was found to be less in patients than in healthy controls in one study.[117] One explanation of this finding is that initial efforts may be inhibited by pain or by the patient's anticipation that they will trigger pain.

Thus, trunk muscle strength is one important factor in assessing the functional capacity of the lumbar spine and, because improvement in muscle bulk cannot be visualized, mechanical devices to measure trunk strength indirectly are essential.

Methods of Testing Trunk Strength and Lifting Capacity

Trunk strength measures, as used here, refer to tests that measure the isolated functional capacity of what has been termed the lumbo-

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pelvic functional unit. This unit is defined as the anatomic segment between the scapula and the femur that transmits the axial forces involved in bending, lifting, and ambulation. This definition distinguishes trunk strength measurement from lifting capacity measurement, which involves a whole-body, compound functional unit, a topic that must be considered separately.

Trunk Strength Measurements It is not the purpose of this section to detail the various commercial devices currently available for research or clinical use in testing both isolated trunk strength and lifting capacity. It is currently impossible to separate the claims made for these instruments from their value as simple measurement tools. This will only be possible with more basic technical research. In the past, measurement has never been a major part of spinal diagnosis, and thus the availability of potentially objective devices for this purpose is of great interest.

Although much experimental work has been done on one-of-a-kind laboratory models, a sitting device has been duplicated for use in a few centers by one of the original groups of investigators in the field.[138] This machine consists of a sturdy frame with an extremity dynamometer adapted for trunk strength measures by linking a chest stabilizer through a chain drive. The axis of motion is aligned to approximate the center of motion for the L5-S1 interspace in the sagittal plane. A computer permits summation of key measurements and graphic display. Both isokinetic and isometric test formats can be utilized. Isokinetics permits the control of preselected variables (distance traveled, velocity, and acceleration). Controlling these three variables permits only the torque to vary independently, making it possible for this measurement system to be used in standard protocols for interindividual and sequential intra-individual comparisons. Because the patient is in the sitting position, the trunk is already flexed 90 degrees through a combination of hip and true spinal flexion, so that only limited additional flexion is possible. Extension is possible in at least a 60-degree arc, but this test device does not permit measurements in the posturally neutral (equivalent of erect standing) position. Additionally, nonphysiologic gravity effects must be taken into account because of the semisupine posture that occurs when the subject is in maximal extension. The device is useful solely for sagittal (flexion-extension) measurements.

Other instruments for measuring isokinetic isolated trunk strength in the flexion-extension plane have evolved from this early device. All these devices contain common features. Postural stabilization is produced at the pelvis, and torques are produced around an axis estimated to be at the L5 level. Most devices operate in a single plane. None of the devices fully stabilizes the hips, so that some hip motion must accompany spinal motion in the sagittal plane. A dynamometer attached to the chest wall measures the torque via a hydraulic or electromechanical apparatus and displays both graphic and numeric information on a computer monitor.

Newer devices for axial-plane measurement involve a sitting posture with the hips stabilized in the abducted position. The dynamometer is mounted overhead to permit spinal rotational motion.

Lifting Strength Measurements   Isokinetic-isometric lifting devices connect the dynamometer to a cable or a mobile arm, allowing simulation of a lifting maneuver. Comparisons between individuals in lifting generally necessitate either an ergonomic (standard height) or anthropometric (standard anatomic points, such as floor to waist) protocol. Lifting, being a compound maneuver of multiple functional units, does not involve anatomic stabilization. Thus, it permits a variety of lifting styles that allow the individual to substitute one functional unit for another and to choose between efficiency and safety. Such substitution is not possible in isolated trunk strength testing modes, which limit the options.

In addition to isokinetic lift testing, other methods are available. Isometric strength testing has been advocated for many years, predominantly by industrial engineers.[139-141] Recent work appears to indicate that isometric and dynamic isokinetic tests do not correlate well.

Isoinertial-psychophysical lifting tests also have a long history,[142] but have only recently come into the clinical arena.[136,137,143] These methods lack the sensitivity and specificity of isokinetic dynamic testing because they fail to control the speed and acceleration variables in order to leave isolated torque as the only independent strength variable. It seems likely that no single system is sufficient for measuring this compound total-body activity in a relevant manner, as recent work has shown only moderate correlation between the dynamic isokinetic and isoinertial modes of testing in identical subjects.[136,137] This is not surprising, since the velocity and acceleration techniques customarily employed by trained lifters are isokinetic. Such techniques are unconstrained in an isoinertial lift.

Trunk Strength as a Risk Factor in Low Back Pain

Prospective longitudinal studies have addressed the issue of the association between the strength of the trunk musculature and low back disorders.[144-146] Poor abdominal muscle function in a sit-up usually improves with remission of low back pain. Rowe[145] also observed that 50% of patients who had episodes of low back pain that caused disability had demonstrated poor abdominal muscle function before the episode. However, during a one-year prospective population-based study, isometric strength of the trunk muscles did not predict the appearance of low back problems.[146] In that study there was some evidence that isometric endurance, rather than strength, might predict low back pain incidents in men but not in women.

In another study involving more than 2,000 industrial workers (office and heavy-labor jobs),[144] a subset of several hundred performed muscle-function tests involving trunk muscle strength. The major correlation observed was between trunk muscle strength tests and clinical

tests that qualitatively assessed flexibility and discomfort on palpati
Both men and women with palpation discomfort and reduced mobi
at the beginning of the study tended to have the poorest performa:
on the muscle-function tests performed ten years later. This associat
between evaluation scores on the clinical tests and the later musc
function tests supports the view that both abnormalities, for whate
the reason, affect trunk muscle performance over time. On the oth
hand, the results of the dynamic muscle-function tests (sit-ups a
prone trunk extension) performed at the beginning of the study w
associated with the later appearance of clinical findings in men l
not in women. Therefore, the functional status of the trunk musc
may also have predictive implications for the later development
low back problems. These investigators suggested that trunk musc
may thus be important in causing such problems and the effects
other abnormalities that alter trunk muscle performance may be s
nificant factors in low back pain.

The Effects of Exercise

General Considerations

In a general sense, human performance is highly dependent on mu
cle function. Motion provides beneficial effects to muscle tissue as we
as to joints, while exercise (resistance) and degree of aerobic fitne
also benefit muscles.[147-150] By contrast, immobilization produces mu
tiple detrimental effects not only on muscle but on all soft tissue
including cartilage, tendon, ligament, and disks.[148,150-158] Thus, there
substantial evidence that maintenance of function is a powerful h
meostatic mechanism, with decreases in activity being associated wit
adverse effects on all tissues of mesothelial origin. Resumption of a
tivity after injury maintains the physical capacity of the uninjure
structures and promotes more rapid healing in the injured tissues. Fc
example, evidence is accumulating that different collagen-based tissue
recognize particular types of stress and align themselves along specifi
pathways when responding to both daily activities and injur
(overload).[147,150,159]

The Effects of Exercise on Trunk Muscle Performance

In the specific case of the spinal muscles, these broad principles hav
also been held to be important. Traditionally, sit-ups have been rec
ommended not only for treatment of low back pain, but for its pre
vention. Longitudinal studies have shown that sit-ups increase en
durance for trunk flexion but improvements in strength have been les
convincing.[160-163] Similar results have been reported for the prone trunk
extension exercise. Electrical stimulation of trunk muscles results ii
an increase in endurance but not in strength.[124]

Part of the problem in assessing these results is that active exercise:
such as sit-ups, double leg-lowering, and prone trunk-extension have

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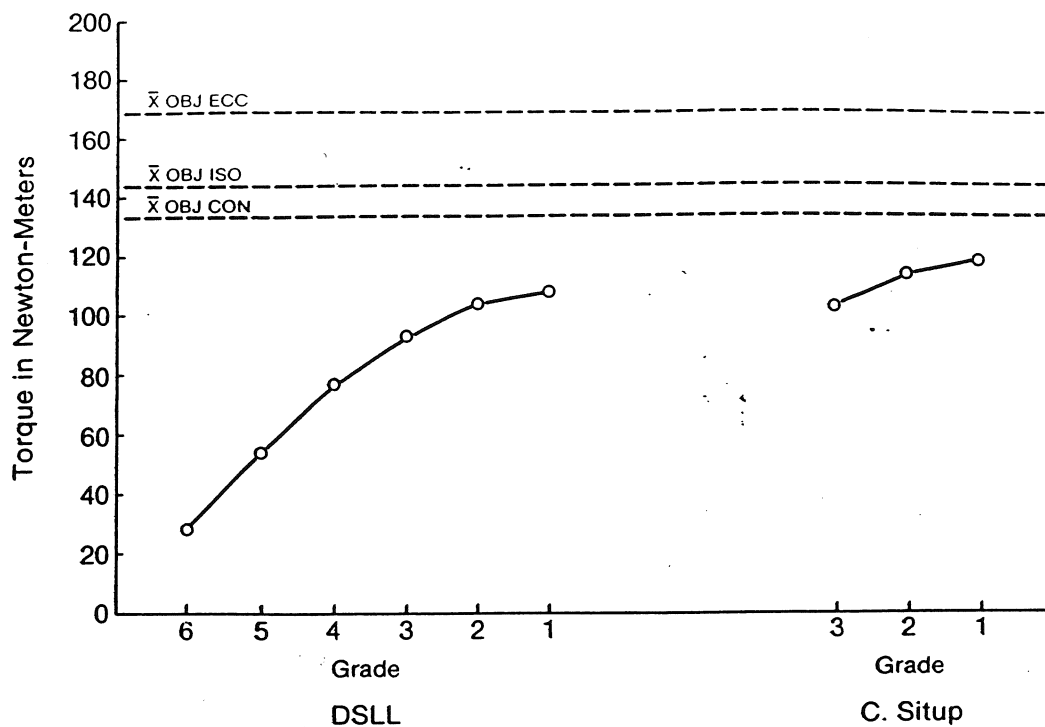
Fig. 7A-1 *Calculated estimates of trunk flexor resistance imposed by the different grades of double straight-leg-lowering (DSLL) and conventional sit-up (C. Situp) in relation to the maximal strength measures. Mean strength was obtained for 38 healthy subjects who performed concentric (CQN), isometric (ISO), and eccentric (ECC) muscle contractions. For sit-up, grade 1 = hands beside neck; grade 2 = arms across chest; and grade 3 = arms reaching forward. For DSLL, 0 degrees = the horizontal position; grade 1 = 0 degrees or the horizontal position; grade 2 = 15 degrees; grade 3 = 30 degrees; grade 4 = 45 degrees; grade 5 = 60 degrees; and grade 6 = 75 degrees. (Reproduced with permission from Smidt GL, Blanpied PR: Analysis of strength tests and resistive exercises commonly used for low back disorders. Spine, in press.)*

significant limitations when they are used as tests of abdominal strength because they discriminate poorly for the level of strength. When these techniques are used as strengthening exercises for the trunk muscles, they do not appear, in most people, to provide resistance sufficient to maximize abdominal strength (Fig. 7A-1).[125,126]

In contrast, increases in peak muscle strength have been consistently demonstrated when maximal voluntary trunk muscle exercise regimens are extended over a six- to 12-week period.[164,165] However, not enough studies have been conducted to provide guidelines for the strength gains that can be anticipated in differing populations of subjects. Also, no studies have used the same objective method for both

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testing and exercise training. What the influence learning may hav on the objective tests, quite independent of the true strength gair made, is uncertain. In studies using extremity muscles, rapid strengt gains during early strength training have been attributed primarily t neurotrophic influences, whereas subsequent slow strength gains hav been attributed primarily to hypertrophic factors.

Therapeutic Trunk Muscle Exercises in Patients With Low Back Pain

The effects of exercise in patients with low back problems have bee sparingly considered. Mayer and associates[123] reported strength gair in patients with backaches caused by industrial injuries after a three week rehabilitation program that included unspecified exercises, trair ing in functional tasks, education, and work hardening. Analogou measures for an untreated group were not reported.

In 1958, one study reported the effects of high-intensity resistiv abdominal and back extensor exercise on chronic low back symp toms.[108] After 12 weeks, 58% of the group reported complete relief c pain, 31% reported partial relief, and 11% reported no relief. No contro group was included in this study. Another study using maximal isc metric exercise for patients with histories of low back pain demor strated a 22% gain in abdominal strength as a result of a five-wee exercise program.[166] As in more recent investigations, the only me chanical variables reported for muscle function were peak force an torque, both of which, as previously noted, are incorrect measurin techniques.

In a study of 45 young adults by Smidt and associates,[125] the eccentri form of resistive exercise was shown to be superior to concentric rc sistive exercise for the trunk extensors. The six-week training prograr was performed and the tests were conducted with the Kin Com trun testing unit (Fig. 7A-2). After six weeks, the rate of the strength gair for the concentric exercise group was low, whereas the eccentric grou continued to show sharp increases in trunk muscle strength (Fig. 7A-3

The specific exercise regimens that may be used in acute, subacute and chronic low back pain have received a great deal of clinical a tention, but there is only minimal scientific information availabl Deyo[167] extensively reviewed the clinical trials of exercise regimer and found few valid studies. Kendall and Jenkins[168] compared exercis programs and demonstrated that isometric regimens were most eff cacious. These types of programs are stressed in the "low back pai school" approach to treatment.[169] Although exercises are but one pa of this approach, the program was more effective than manipulatio or "detuned" diathermy. However, in another study,[170] the educatio program was more effective than flexion exercises. Recently, extensio exercises have become popular as an effective therapeutic program. comparison of this program with spinal traction or low back scho revealed that the extension regimen resulted in greater subjective reli of symptoms.[171] A recent comparison of spinal flexion and extensio exercises concluded that the two programs were equally effective i
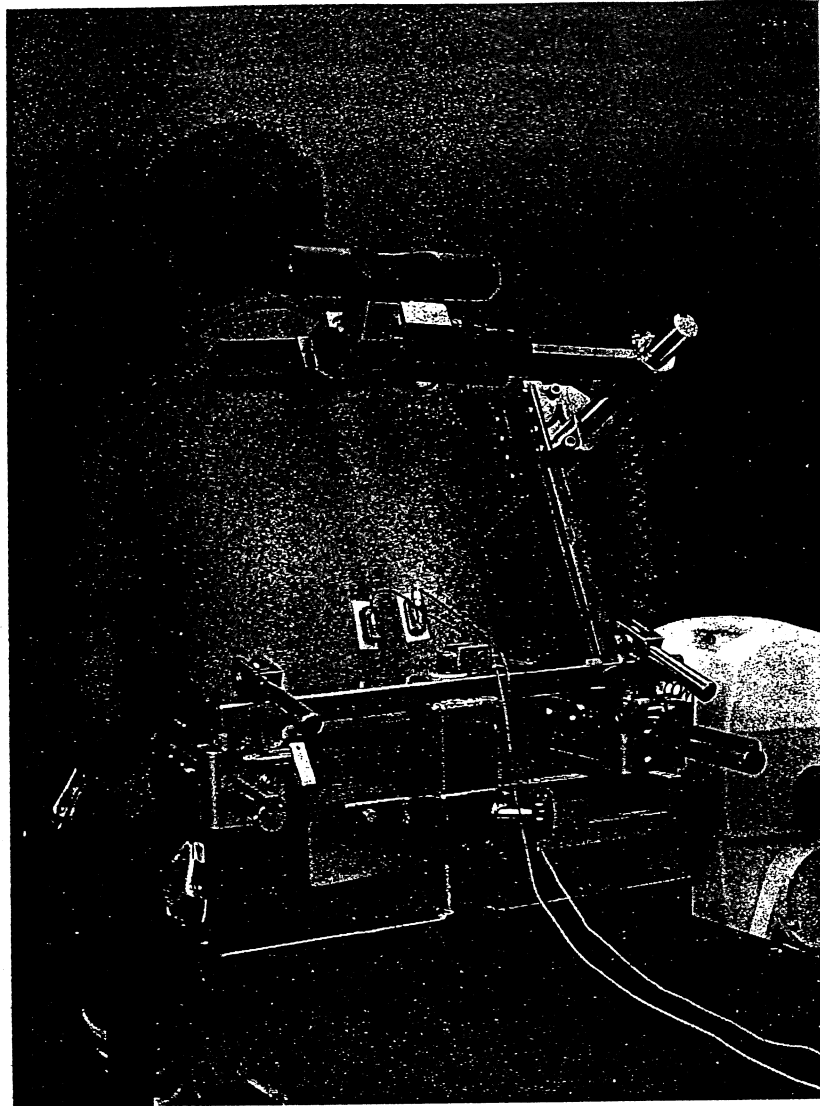
Fig. 7A-2 *Testing unit. Servocontrolled system permits tests of isometric, concentric, and eccentric strength and endurance. Pelvis and thigh are stabilized while testing is conducted with the subject in the seated position. Electromyographic electrodes are placed over the paraspinal muscles of the subject who is shown during a test of trunk extensor function. (Reproduced with permission from Smidt GL, Blanpied PR, Anderson MA, et al: Comparison of clinical and objective methods of assessing trunk muscle strength: An experimental approach.* Spine, *in press.)*

reducing subjective complaints, but the patients who were subjected to the flexion regimen regained a greater degree of sagittal mobility.[172] In addition to these specific exercise programs, many newer approaches

ECCENTRIC EXTENSOR TORQUE
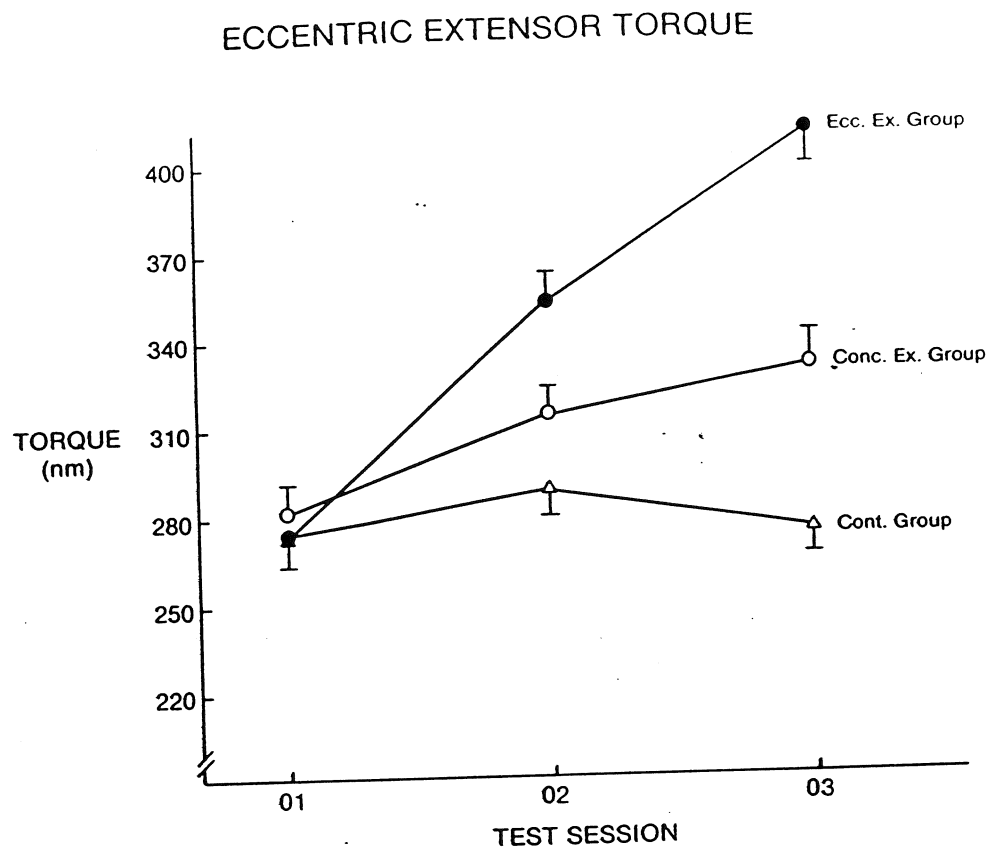
Brackets Indicate 0.1 S.D.

Fig. 7A-3 *Results showing the differences in trunk extensor strength among three groups of subjects: those doing eccentric exercise (Ecc. Ex.), those doing concentric exercise (Conc. Ex.), and the control (Cont.) group. Test session 01 is at baseline, 02 is at two weeks, and 03 is at six weeks. (Reproduced with permission from Smidt GL, Blanpied PR, Anderson MA, et al: Comparison of clinical and objective methods of assessing trunk muscle strength: An experimental approach. Spine, in press.)*

are directed to general aerobic reconditioning. Although many studies of the possible beneficial effect of such programs on disk nutrition, spinal mechanics, and pain modulation have been published, no carefully controlled studies have isolated these programs from a more general approach to acute and chronic low back pain.[173-176]

Back Muscle Fatigue

Introduction and Background

Back muscle fatigue has been of interest to investigators over the years. Although the term "muscular insufficiency" has been used in

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many studies, suggesting that muscles cause symptoms, the role of muscular insufficiency in the development and treatment of low back pain remains an enigma. Early detection and precise evaluation of back muscle fatigue is of practical importance, for it has been theorized that the structures constituting the functional spinal unit are increasingly subject to mechanical stresses when muscular support is inadequate.[177] Recent evidence has shown that deficiencies in the lumbar musculature are often associated with chronic low back pain.[178,179] Other studies have shown that normal muscle is disrupted in patients with low back pain.[90,180-184] This assertion is also supported by the high incidence of back injuries in workers exposed to whole-body vibration or repeated heavy manual tasks, both of which are associated with myoelectric evidence of muscle fatigue. Yet another postulated mechanism is the reduction of precise motor control that accompanies muscular fatigue.[185] The industrial engineering literature contains many observations indicating that motor control is affected by fatigue in the work setting.[186-191]

Fatigue, as defined in mechanical terms, is the point at which a contraction can no longer be maintained at a certain level (isometric fatigue), or when repetitive work can no longer be sustained at a certain output (dynamic fatigue). In both cases, the mechanical events are preceded by biochemical and physiologic events within the muscle, not measurable in mechanical performance. Furthermore, the mechanical parameters of fatigue—failure to maintain a posture, exertion, or pace of work—are highly subjective phenomena and thus influenced greatly by motivation. More objective biochemical and physiologic parameters, therefore, have attracted increasing interest. Biochemical parameters must be sampled invasively, and therefore physiologic parameters of fatigue have been particularly promising in spinal muscles, because they can be monitored by electromyographic electrodes placed on the body surface. In the discussion that follows, fatigue studies of spinal muscles are separated into those dealing with mechanical and those dealing with electromyographic measurements. To date, no biochemical studies specific to the back have been done.

Mechanical Studies of Fatigue (Endurance)

Mechanical tests of trunk muscle endurance have included maintaining a posture[115,132,146,192] and performing an activity repeatedly.[117,121,193]

Nordin and associates[115] used a postural endurance test to study a group of normal females. This test was performed on a subject in the supine position with the unsupported trunk held in a horizontal position for as long as possible, up to a limit of 240 seconds, a technique previously used by Biering-Sørensen.[146]

Nicolaisen and Jørgensen[132] performed such studies of isometric endurance and found that patients with low back pain had significantly shorter endurance than controls. Despite the differences in endurance, there were no differences in isometric back muscle strength between patients and controls. Nicolaisen and Jørgensen also used another endurance test method, the so-called 60% maximum voluntary contraction isometric endurance time. This is the time for which a contraction

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that is 60% of the maximum can be sustained. This test yielded similar results. In a subsequent study, Jørgensen and Nicolaisen[192] studied trunk extensor endurance in back patients and pain-free subjects. Back muscle endurance was determined by instructing the subjects to perform sustained, isometric contractions using their back extensors while the investigators monitored the time until exhaustion. They found that back muscles have a relatively longer endurance capacity than other muscle groups. They attributed this to the fiber composition of the back muscle (largely slow-twitch, oxidative fibers). To account for this endurance, they also postulated that back muscles are able to mobilize more perfusion than other muscles. They also found that persons with earlier serious attacks of low back pain had less endurance capacity than normal subjects but similar strength in their trunk extensors. This result was tentatively explained by a possible difference in the fiber compositions of the back muscle in patients and normal subjects: the composition of back muscle in the patients was dominated by a greater proportion of easily fatigable, type II fibers. They speculated that, as a consequence, such individuals are exposed to postural stress and impaired coordination of the postural muscles.

Nordin and associates[193] recently conducted a study in which they used a triaxial dynamometer to measure torques, angular positions, and angular velocities while the subjects, who were in upright postures, moved through a flexion-extension arch repeatedly until fatigue developed. Their findings can be summarized as follows:

The ranges of motion in the sagittal, coronal, and transverse planes were significantly affected during fatiguing isoinertial movement. As the muscles fatigued, range of motion increased in the secondary planes of motion, the coronal and transverse planes, indicating diminishing control and coordination of the fatigued neuromuscular system. Concomitantly, range of motion decreased in the sagittal plane, the primary plane of motion that they were studying. This result was interpreted to mean that there was a tendency toward task aversion, as well as a reduction in the accuracy and reproducibility of position profile.

The maximum and average velocities in the sagittal and coronal planes were changed significantly by fatiguing isoinertial movement. The decreased maximum and average velocities in the sagittal plane indicated a reduction in the rate of muscle contraction; however, the increased velocities in the coronal plane resulted from reduced coordination. This reduction in speed, caused by fatigue in the primary plane of motion, appeared to compromise the subjects' ability to compensate for load perturbations. This reduction also introduced time delays in the neuromuscular system, thus theoretically increasing the instability of the spinal support musculature, with a potential for load shifts.

The reduced torque, total angular excursion, and angular velocity indicated a reduction in work and the power generated by the subject as the fatiguing movement continued.

Thus, the most deleterious effects of the neuromuscular adaptation

to fatigue were the reductions in accuracy, control, and the speed of contraction, which might predispose an individual to injury.

Electromyographic Studies of Fatigue

Surface electromyography has been the other major technique used to study the fatigue properties of back muscles. Before recent technical advances, most electromyographic studies of the back were kinesiologic attempts to relate back muscle activity to different postures and loads. The major technical advance has been detection of electromyographic signals with power spectrum analysis for the quantification of localized muscle fatigue. This technique measures the shift in the electromyographic power spectrum associated with the biochemical events that occur during a sustained contraction. Analysis of time-dependent modification of the electromyographic signal has led to the characterization of muscle fatigue as a continuous process. The compression of the electromyographic power spectrum toward lower frequencies during a sustained contraction has been observed in a variety of muscles.[194] Stulen and De Luca[195] explained that a relationship exists between the shift of the power spectrum toward lower frequencies and the increase in amplitude of the electromyographic signal. They observed that the low-frequency components of the electromyographic signal increase during a sustained contraction. As a result, more of the electromyographic signal's energy passes through the low-pass filtering effect of the tissue. Several factors have been proposed to explain the modifications to the surface electromyographic signal that occur during a fatiguing contraction. These include changes in the firing rates and statistics of motor units and changes in the conduction velocity of the motor-unit action potentials.

One of the earliest studies of the relationship between the electromyographic signal of the lumbar musculature and the external work of the back was performed by Morioka.[196] He observed a decrease in the electromyographic signal amplitude and an increase in low-frequency potentials while subjects performed static lifting at 20% and 30% of their maximum capacity. In a study of prolonged isometric contractions of the erectores spinae muscles, Chapman and Troup[197] observed a decrease in the total electrical activity during the onset of fatigue symptoms. They attributed this decrease to a transfer of activity to other muscles in the trunk; however, in a subsequent study,[198] they found that the integrated electromyographic signal increased with fatigue. They suggested that this inconsistency resulted from their failure to account for movements of the pelvis in their first study. This may have resulted in changes in posture and, thus, changes in back muscle length.

Okada and associates[199] studied the endurance capacity of the lower back muscles during static work. Bilateral surface electrodes were used to record the electromyographic signal from the erectores spinae muscles at the fourth lumbar level. Eight subjects were tested. Each subject was placed in 30% flexion and then performed sustained contractions at 30%, 40%, 50%, and 70% of the maximum for as long as possible

before the onset of pain. The electromyographic signal was integrated and a frequency analysis was performed. Okada and associates discovered that the electromyographic signal increased initially with fatigue, but decreased persistently in the contraction's later stages. This suggested that the subjects may have altered their posture to alleviate muscular pain. They also observed that the low-frequency components of the electromyographic power spectrum increased consistently throughout the contraction.

Andersson and associates[60] studied quantitatively the electromyographic activity of the erectores spinae muscles while the spine was loaded in different postures. Using bipolar surface electrodes, they recorded the electromyographic signal at levels T4, T8, L1, L3, and L5. Their results showed increases in electromyographic signal amplitudes at all levels of the back when the angle of forward trunk flexion was increased from 10 to 50 degrees. With respect to endurance, they observed significant spectral changes in those test positions that produced high electromyographic signal amplitudes. Furthermore, they found that an increased level of electromyographic activity was also accompanied by an increased rate of change in the electromyographic power spectrum.

Jayasinghe and associates[200] recorded the electromyographic signal from the left and right sacrospinalis muscles at levels L4 and L5 while the subject was standing erect. They performed these experiments on controls and back patients and found that the patients exhibited a general pattern characterized by an increase in the mean-square value of the electromyographic signal as a function of time. In contrast, the controls showed a decrease in the mean-square value of the electromyographic signal with time. They concluded that muscle weakness or fatigue is associated with low back pain.

Roy and associates[178] described an electromyographic signal-processing device that calculates the median frequency of the electromyographic signal in real-time using analog circuitry. This system is presently configured to process up to ten electromyographic channels and two force channels. They concluded that the median frequency of the electromyographic signal is related to the accumulation of metabolites in the muscle fibers. They reported that changes in the median frequency as a function of time provide a biochemically related index of muscle fatigue during sustained contractions. The median frequency index differs from the classic contraction force index as a measure of muscle fatigue by virtue of the fact that median frequency begins to decrease at the beginning of a contraction, even if the contraction is maintained at constant force. This permits assessment of the fatigability of a contracting muscle in situ without exhausting the subject to contractile failure.[194]

Roy and associates[178] combined the electromyographic signal-processing device with a postural restraint device and torque measurements (Fig. 7A-4). The restraint device and force-acquisition system were designed to ensure that the sustained isometric muscle activity observed was actually associated with the extension torque being mon-

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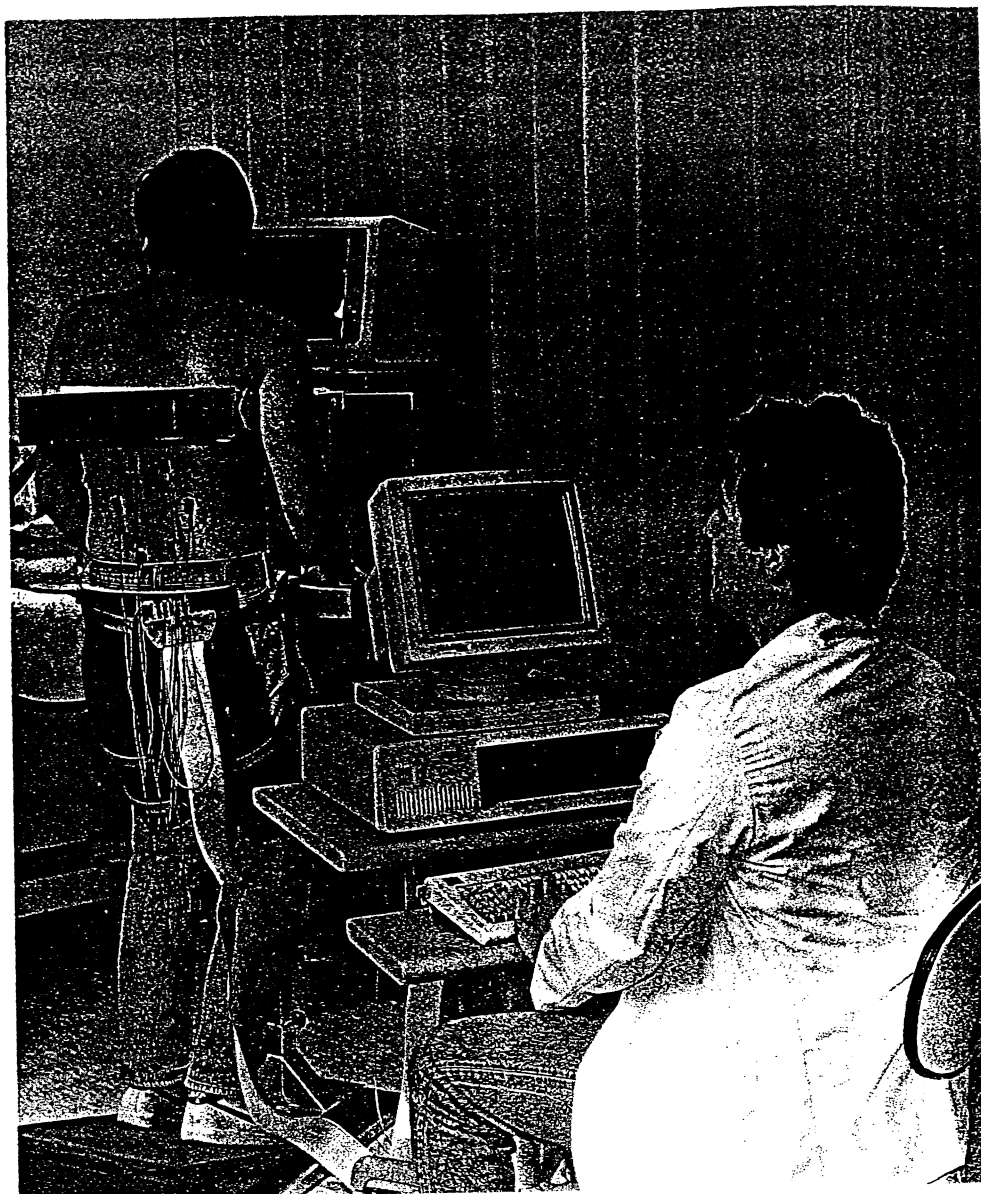
Fig. 7A–4 *The back analysis system for evaluating fatigue-related insufficiencies in lumbar muscles. The postural restraint device and the muscle fatigue monitor with computer are shown.*

itored. This device has been used to assess the condition of patients with previous or current low back pain by evaluating the fatigue characteristics of their back muscles during sustained, constant-force trunk
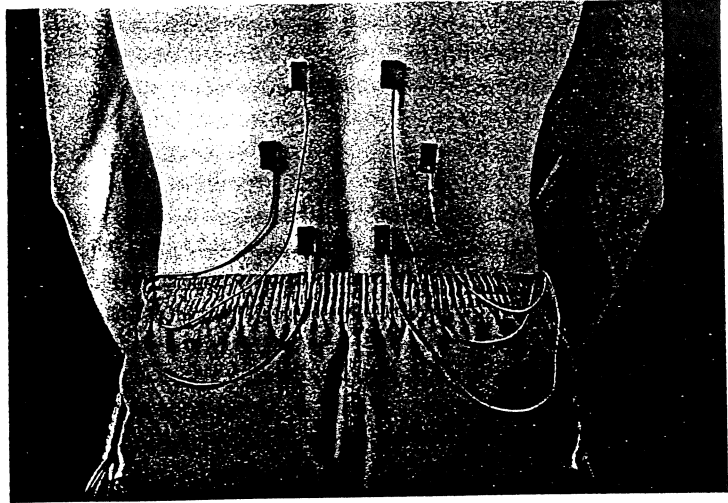
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Fig. 7A–5 *Typical placement of six active surface electromyographic electrodes corresponding to the approximate bilateral locations of the longissimus (L1), iliocostalis (L2), and erector spinae (L5) muscles.*

extension. The premise being evaluated was that the postulated muscle imbalance should be evident during a fatiguing contraction. The potential advantage of this approach is that it eliminates subjective factors such as the patient's motivation. These preliminary investigations included reliability studies and comparisons of patients with chronic back pain and control subjects.

Reliability studies were conducted on a group of eight subjects who performed repeated contractions at 90% of maximum on the same day and on consecutive days. The duration for each contraction was 30 seconds; when the tests were repeated on the same day, a 15-minute rest period was allowed between tests. In these tests, six electrode locations were used (Fig. 7A–5) to monitor bilateral paraspinal muscle activity and at different lumbar spinal levels. The parameters of interest included the initial median frequency and the slope of the regression line calculated for each of the median frequency curves. A single-factor analysis of variance procedure was used to estimate the reliability of the measurements. From this analysis, a reliability estimate was computed from the variance of the true measurement divided by the sum of the variance of the true measurement and variance due to the mean of the measurement errors.

The reliability estimates calculated for measurements recorded on the same day were 0.98 and 0.94, for the initial median frequency and the median frequency slope coefficient, respectively. For measurements taken on consecutive days, a slightly higher variability in experimental "error" was observed. The calculated reliability estimates

were 0.83 for the initial median frequency and 0.73 for the median frequency slope coefficient.

Twelve patients, in remission, with histories of chronic back pain of unknown origin (no skeletal abnormalities on radiographs or computed tomographic scan) were tested and compared to normal controls. After the acquisition of the subject's maximal voluntary contraction and a five-minute rest, the subject performed a 40% of maximum contraction for one minute. After a 15-minute rest, the subject performed a 60% of maximum contraction for one minute. The subject was then allowed another rest period of 15 minutes. A third contraction was performed at 80% of maximum for 30 seconds. Figures 7A-6 and 7A-7 summarize the data for initial median frequency and slope of the median frequency. The patients were able to generate force levels similar to those of controls, consistent with results obtained by Jørgensen and Nicolaisen.[192] The decrease in initial median frequency, with increasing force level shown in Figure 7A-6 suggests that smaller fibers are recruited at higher force levels. This is based on the observation that the initial median frequency reflects the conduction velocity of the muscle fiber, and is therefore related to the size of the muscle fibers.[194] This observation is consistent with reported autopsy and biopsy studies that indicate that type II fibers, which are recruited later, have smaller mean diameters than type I fibers in human trunk extensor muscles.[201-203]

A comparison of initial median frequency values in patients with low back pain and controls showed a significant group difference only in measurements obtained from the longissimus muscle at level L1. Specifically, at this level, the mean values were 10% to 15% higher in controls than in patients; this difference was consistent at all three percentages of maximum voluntary contraction. This difference may exist because the longissimus muscle át level L1 has a greater proportion of smaller-diameter, type II fibers in patients than in controls. An alternative hypothesis is that back patients have smaller muscle fibers as a result of atrophy.

Both patients and controls exhibited a trend toward increasing fatigue rates with increasing force (Fig. 7A-7), which is a commonly observed tendency in limb muscles.[204] This trend is hypothsized to be the result of either increased metabolic accumulation rates with increasing force because of a greater number of active motor units and/or reduced circulation or recruitment of easily fatigable type II fibers with increasing force.

The measured fatigue rates of the individual back muscles differed significantly in the patient and control groups. Specifically, the erector spinae (L5 level) and iliocostalis (L2 level) muscles demonstrated reliably higher fatigue rates at the 80% contraction level (Fig. 7A-8). Such group differences in fatigue rate were not identified at the 40% or 60% contraction levels. However, the longissimus muscle (level L1) demonstrated no group differences at any of the three contraction levels.

The higher fatigue rates observed in the patients were consistent with previous observations.[132,184,192,200] However, previous investigators
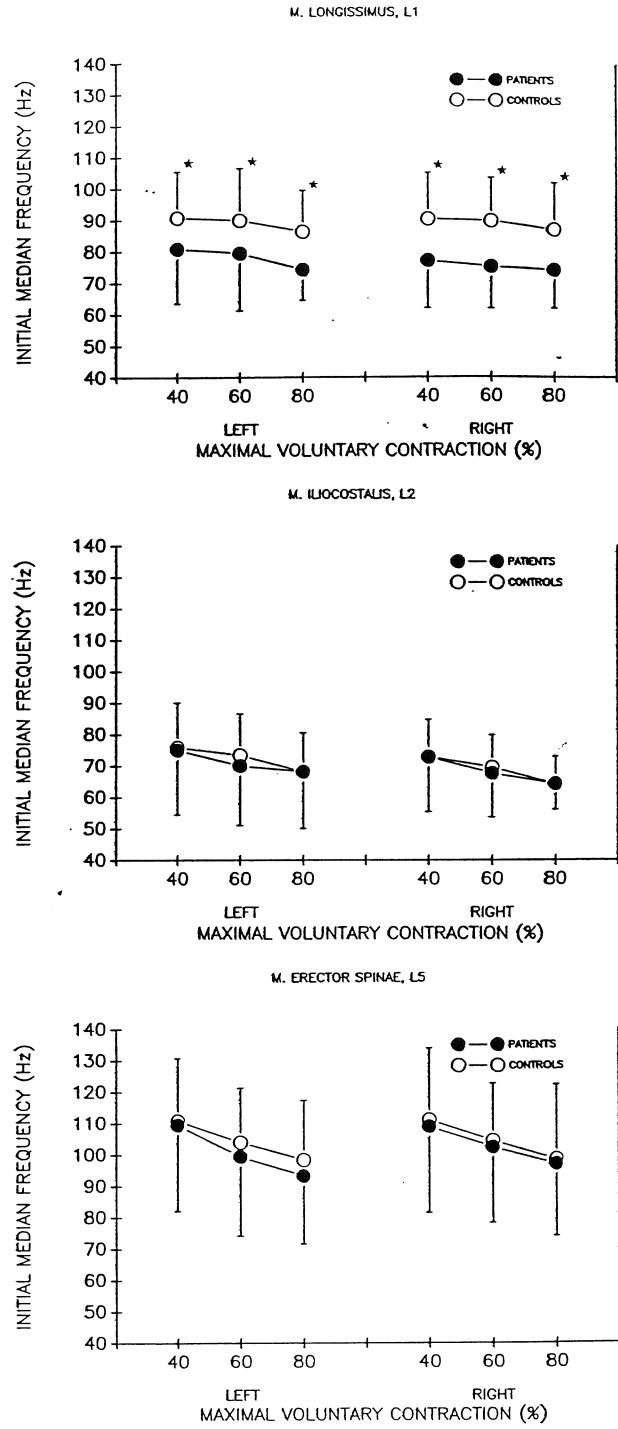
Fig. 7A–6 *Mean initial median frequency for left- and right-sided muscles at the three target force levels tested in the longissimus (top), iliocostalis (center), and erector spinae (bottom) muscles. P < .05 for the significance of difference between means.*

M. LONGISSIMUS, L1

M. ILIOCOSTALIS, L2
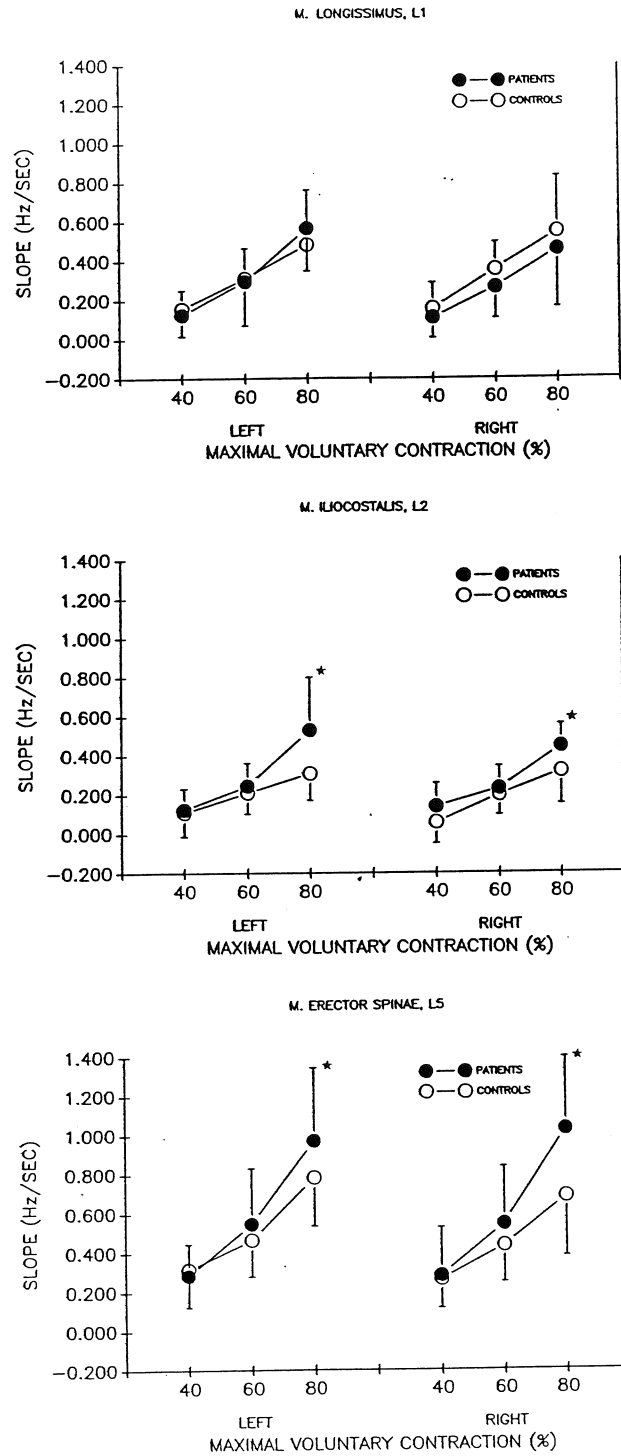
M. ERECTOR SPINAE, L5

Fig. 7A-7 *Mean slope coefficient of median frequency for left- and right-sided muscles at the three target force levels tested in the longissimus (top), iliocostalis (center), and erector spinae (bottom) muscles. P < .05 for significance of difference between means.*

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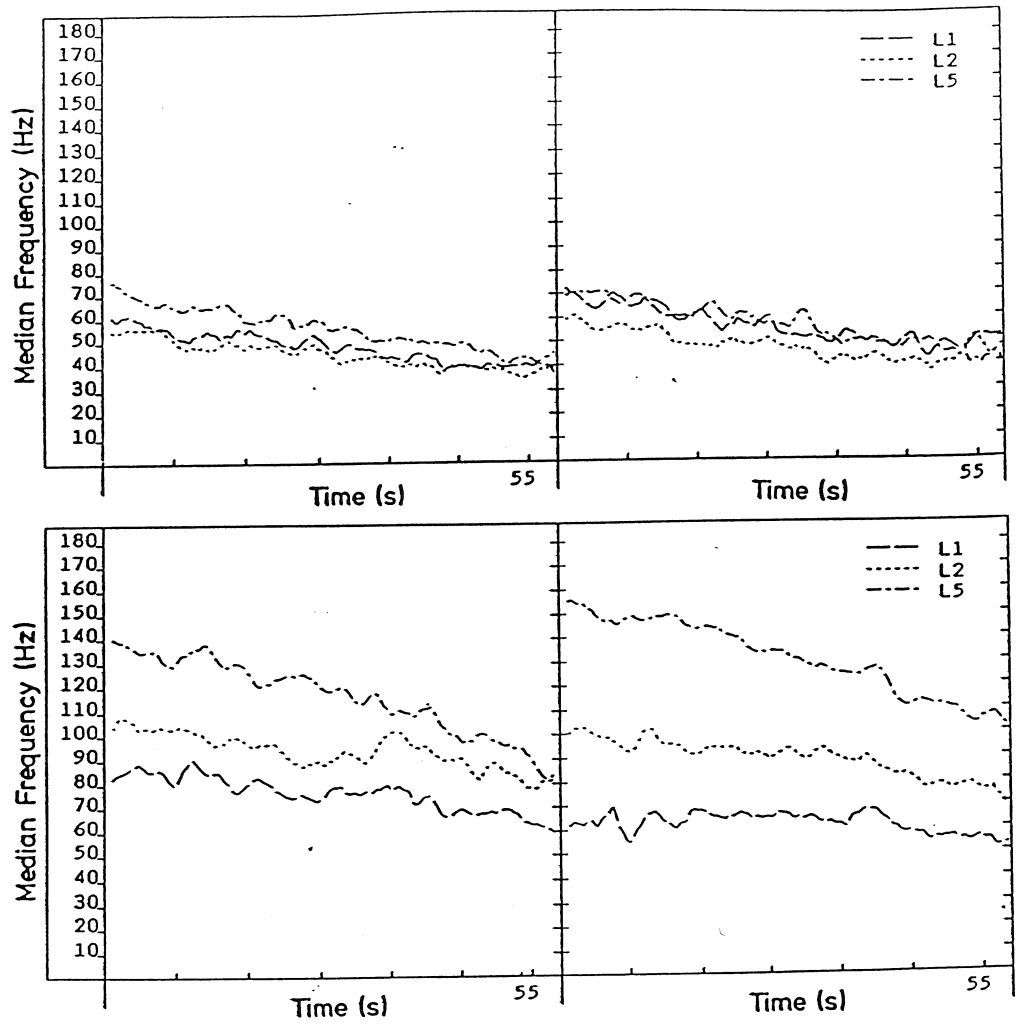
Fig. 7A–8 *Median frequency curves for the six lumbar back muscles tested at 80% of maximum in a control subject (top) and a patient with chronic back pain (bottom). Curves are arranged in groups of three, corresponding to left- and right-sided muscles.*

used different measurements of endurance. For example, deVries[18] and Jayasinghe and associates[200] measured changes in temporal electromyographic activity and Nicolaisen and Jørgensen[132,192] measured time until exhaustion. All these studies suggest an association between chronic back pain and deficient trunk extensor endurance.

A variety of alternative hypotheses may explain these higher ob-

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Table 7A-1 Muscle function in high-performance athletes*

Lumbar Level	No. of Subjects	% Classified Correctly†	Variables Used in Classification
L2			% recovery at 1 min‡; initial median frequency of contraction‡; rate of median frequency decay during contraction‡
Port rowers	13	91	
Starboard rowers	10	70	
L5			% recovery at 1 min§
Without low back pain	17	77	
With low back pain	6	83	

*Based on data from Roy and associates.[178]
†Acceptable level, ≥75%.
‡Right side tested.
§Both sides tested.

served fatigue rates in back patients. Among these are deficient endurance capacity and a predisposition to more rapid fatigue resulting from higher precontraction metabolic accumulations that may be caused by persistent muscle spasm and prolonged muscle tension. A further possibility, which cannot be tested at this time, is that the erectores spinae muscles at the L2 and L5 levels are active at a relatively greater force level of contraction than other muscle groups.

In addition to analyses of fatigue rate, studies have been conducted to measure muscle imbalance. Roy and associates[178] observed consistent left-right imbalances in fatigue and activity levels in both patients and controls, but discerned no significant differences. In contrast, Jayasinghe and associates[200] and Collins and associates[205] observed inconsistent left-right differences in both patients and normal subjects, especially during exertive tasks. Hoyt and associates,[206] however, observed larger absolute left-right differences in activity levels in back patients than in controls. Cram and Steger[183] observed left-right imbalances in patients with low back pain but had no comparison group without low back pain.

The investigation of Roy and associates[178] also included studies of muscle function in high-performance athletes. They studied 23 members of a men's varsity crew to determine whether their assessment technique could correctly identify those subjects with known histories of chronic back pain solely on the basis of the median frequency measurements. Additional analyses were performed to determine whether the data could discriminate between the port and starboard rowers selected for the study. The protocol was limited to a single 80% of maximum contraction of the back muscles for a 30-second period. In addition, a "recovery" contraction was included at one minute after the initial contraction to determine the percentage of recovery in median frequency.

The results from a two-group, stepwise discriminant analysis are summarized in Table 7A-1. The recovery variable from the right and left side of the back at L5 spinal level correctly identified all but one subject who reported having chronic back pain. There were four false-
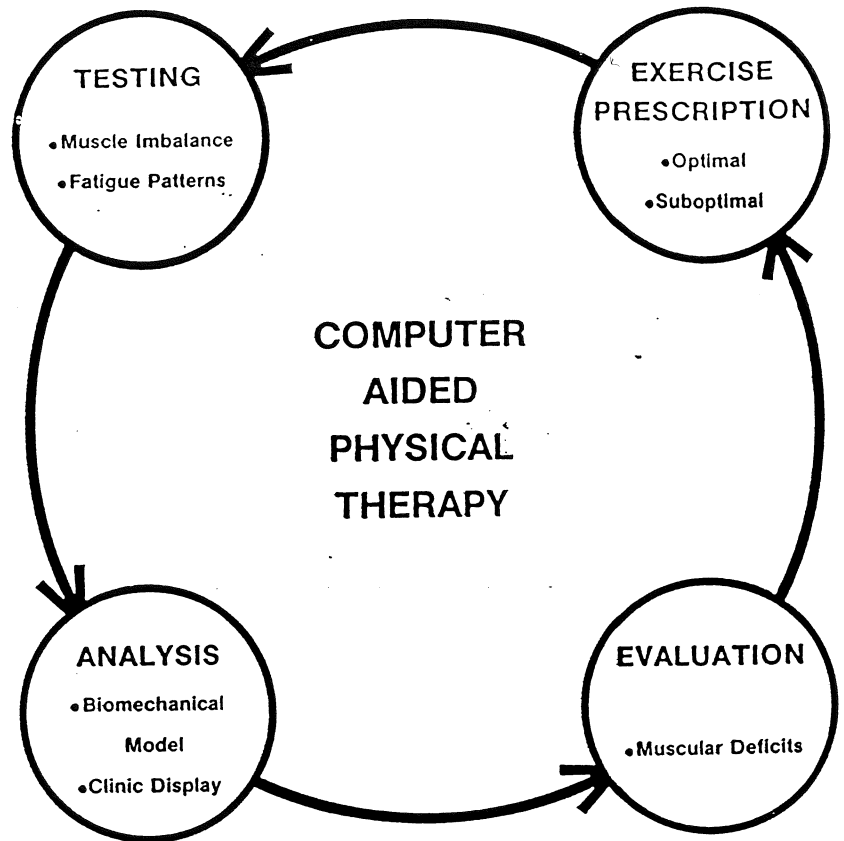
Fig. 7A–9 *Schema representing the four different components proposed for a "computer-aided physical therapy" treatment approach to lower back pain.*

positives in this analysis. The two-group analysis at L2 of all port and starboard rowers correctly classified 90% of the port rowers and 70% of the starboard rowers. Contributing variables, in descending order of discriminating power, were the recovery variable, slope, and initial median frequency, all from the right side of the back. Of the ten starboard rowers, three were incorrectly identified. However, two of these three had been port rowers and had only recently switched to the starboard position.

In comparison to the studies on sedentary subjects, these results indicated that the members of the crew with low back pain had the same endurance capacity as those without histories of back pain. This observation could be interpreted as supportive evidence that extreme exercise regimens in competitive athletes maintain normal muscle function even in individuals with chronic back pain, but whether less rigorous training would have the same effect remains to be determined.

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These data also suggest that certain muscle deficits may still be present despite high levels of training and that these deficits may in some way be associated with the presence of recurrent back pain in these individuals. Results pertaining to the identification of port and starboard rowers further suggest that muscular adaptation to asymmetric tasks is required.

The goal of such studies is to develop a methodology for evaluating and treating low back pain. This schema involves (1) electromyographic testing of the subject to determine muscle imbalances, (2) analysis of the muscle force distribution in the low back by means of a biomechanical model, (3) evaluation of the muscular deficits, and (4) exercise prescriptions to remedy the lumbar muscle insufficiency (Fig. 7A–9).

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