The Lumbar Spine, The Cervical Spine And the Knee

Testing and Rehabilitation

Arthur Jones

Reconstruction of this Manual Courtesy of

Joseph Anderson
and
Brian D. Johnston

INTRODUCTION

Prescribing Optimal Protocols for Rehabilitative Exercise

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Skillfully prescribed strengthening exercise is the most beneficial protocol of treatment during musculoskeletal rehabilitation.

Modern medical care should have the same precision and reproducibility in rehabilitative exercise programs that is expected in a dosage of prescribed medication. By using specific testing and standardized conditions, the dosage of exercise can be brought to the level of accuracy inherent in the prescription of medication.

For exercise to be definable it must be performed in a measurable manner with a specific treatment response in mind. The specific treatment response can only be identified if accurate objective quantification of pre-treatment strength is defined.

In the accurate quantification of strength, these factors must be considered:

Isolation: Accurate measurement, effective neuro-muscular education and muscular overload can only be achieved in an isolated environment.

Non-muscular Torque: Within a joint's range of motion compression of soft tissues and the elastic characteristics of stretched tissues create torque. These factors must be factored into the measured output to correctly assess net muscular torque.

Motion: Movement during testing requires acceleration and velocity; attempts to control these factors create impact forces which inaccurately contribute to measured muscular torque output. Movement also produces friction which is affected by speed and fatigue. Friction and impact forces are essentially unmeasurable and should be eliminated during testing.

Accurate measurement of muscle strength must be done in an isolated static manner. This method of testing allows for the identification and correction of gravity and other sources of nonmuscular torque, and it also eliminates the movement artifacts of impact forces and friction. Static testing allows for a true maximal measure of voluntary effort and accurately co-relates position and torque.

The dose of effective therapeutic exercise can be determined by measuring starting functional ability (strength, range-of-motion and endurance) accurately. The goal is to prescribe a specific dose of exercise that will elicit a predictable, measurable response. The most effective method of testing and prescribing the dose of exercise is the system described in the following pages.

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FOREWORD

by *Arthur Jones*
Founder and retired Chairman of Nautilus Sports/Medical Industries, Inc.,
now Chairman of MedX Corporation.

This book is not intended to be a source of information on the subject of clinical rehabilitation. A supplement written by several doctors will be published during the latter part of 1993, and will provide suggestions for treatment protocols based upon their experience with thousands of chronic spinal patients.

Testing the strength of the muscles that extend the lumbar spine requires total isolation; if the pelvis is free to move, the measured level of torque will be a result of forces produced by muscles of the hips and thighs as well as the muscles of the lower back, and it is then impossible to determine the true strength of the spinal muscles.

In addition to torque actually produced by the force of muscular contraction there are three sources of nonmuscular torque (gravity, friction and stored energy) and these factors must be considered in order to perform a test of true muscular strength.

Strength varies from one position to another throughout any full-range movement, so it is necessary to determine the relative positions of the involved body parts; true changes in strength can be determined only when the tests are conducted in known positions.

Solving all of the problems encountered in the development of equipment that is capable of performing meaningful tests of strength, range of motion and muscular endurance required fourteen years of continuous research; a program of research and development that has now been ongoing for more than twenty-one years. This book outlines the discoveries that resulted from these years of work.

At the moment (March, 1993), the treatment of spinal pathology remains one of the most controversial subjects in the field of medicine; and, in my opinion, a large part of this controversy is a result of the fact that earlier attempts to measure spinal functions were incapable of producing meaningful test results.

Earlier testing procedures ignored a number of important factors that must be considered in order to perform meaningful tests of spinal functions, and this book is primarily intended to explain these factors.

CHAPTER 1

SPECIFIC TESTING FOR SPINAL EVALUATION

Evaluation of functional improvement during rehabilitation must be based on objective test results. Changes in strength, endurance and range of motion can provide the required information if the tests are both specific and accurate; but the requirements for valid testing must be clearly understood and applied.

FIGURE 1-1 Meaningful testing of the muscles that extend the lumbar spine involves several considerations:

1 ... The lower spine must be isolated by anchoring the pelvis, to remove forces produced by muscles of the hips and thighs.
2 ... The torso, head and arms must be counterweighted to compensate for torque produced by gravity acting upon the mass of these body parts.
3 ... All other sources of nonmuscular torque must be measured by the machine and factored into test results by the computer.
4 ... True muscular strength must be measured in several positions throughout a full range of movement.
5 ... Tested levels of strength must be correlated with the positions in which they were measured.

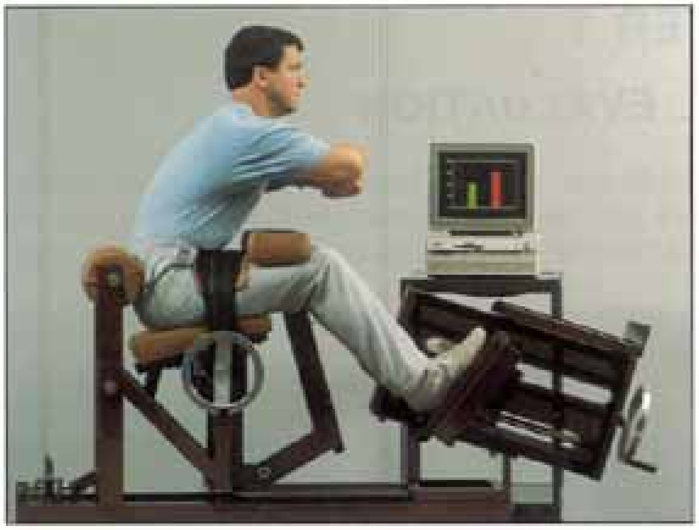


FIGURE 1-2 Used only for demonstrating the system required to isolate the lumbar spine, this machine has no clinical application. During medical seminars, the audience cannot see how this system works if a clinical model of the lumbar-extension machine is used for the demonstration. But with this very simple machine, the audience can see exactly what is happening. First we show what happens without proper restraint: the pelvis rotating as the subject moves. Then we show what happens when the subject is properly restrained: full-range movement with no pelvic rotation, totally isolated lumbar-spinal movement.

Isolating the lumbar spine requires four restraint features:

1 . . . Force imposed against the bottom of the feet is transmitted by the lower legs to the femurs at an angle of approximately 45 degrees.

2 . . . Large pads located above the lower thighs limit upwards movement of the knees.

3 . . .A heavy belt prevents upwards movement of the upper thighs and pelvis.

4 . . . A round pad prevents movement of the pelvis in the direction of extension.

With this system of restraint, the heavy belt above the upper thighs becomes a fulcrum that redirects the upwards force against the knees to a downwards force that prevents the pelvis from rising; one pound of force pushing the knees up becomes approximately two pounds of force holding the pelvis down. The result being forces imposed on the pelvis from two directions; force acting toward, the rear along; the midline of the femurs, and force holding the pelvic/hip sockets down. Properly restrained in this machine, unwanted movement of the pelvis cannot occur during testing or exercise of the isolated muscles that extend the lumbar spine.

The two colored bar-graphs shown on the computer monitor are measurements of force; the red bar-graph is a measurement of force imposed on the bottom of the feet, while the green bar-graph shows force pushing the femurs back against the pelvic/hip sockets.

Without this total restraint of the pelvis, force from the muscles of the hips and thighs would make it impossible to test the actual strength of the muscles that extend the lumbar spine; and movement of the pelvis would make it impossible to determine the
true range of isolated lumbar-spinal movement. During testing and exercise, the muscles of the hips and thighs will attempt to move the pelvis in the direction of extension; but rather than creating a problem, this helps to provide the solution; because the forces from the hip and thigh muscles push the pelvis solidly against the pelvic-restraint pad, and prevent pelvic movement rather than causing it.

No attempt is made to prevent forward movement of the top of the pelvis; doing so would be a mistake. During testing and exercise in the lumbar extension machine, there is no tendency for the top of the pelvis to move forward, so limiting such movement of the pelvis is not required; but if this movement was restricted, it would be impossible to determine the true range of isolated lumbar-spinal movement towards the flexed position.

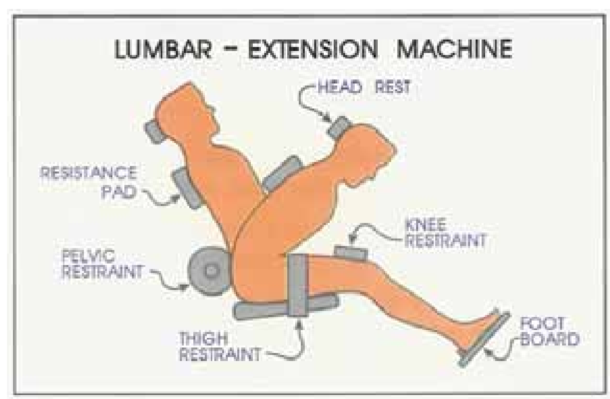


FIGURE 1-3 Spinal isolation system.

FIGURE 1-4 Turning this crank produces force against the bottom of the feet.

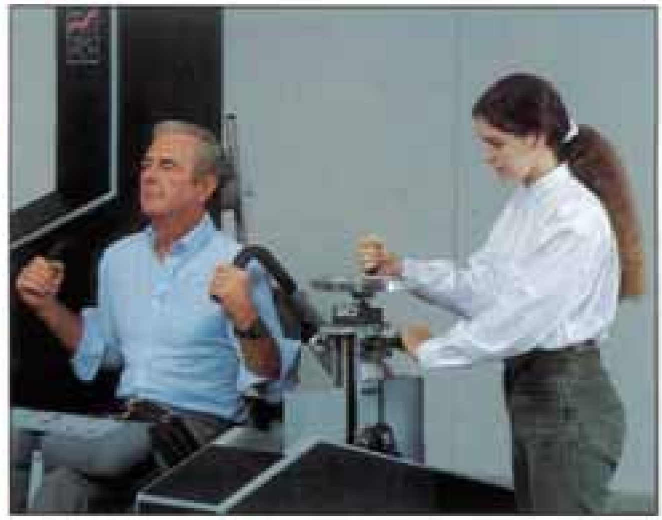


FIGURE 1-6 Before counterweighting can be performed, the centerline of torso mass must be determined and the counterweight connected in an opposite direction; when the subject is sitting straight up, the counterweight must be straight down.

FIGURE 1-5 This crank tightens the heavy belt above the upper thighs to prevent upwards movement of the pelvis.

FIGURE 1-7 With subject relaxed in the extended position, the counterweight is adjusted by turning this crank until balance is provided; when properly adjusted, the weight of the body parts is balanced by the torque from the counterweight acting in an opposite direction. Proper counterweighting is clearly established by the computer monitor, which will tell you when the subject is balanced.

FIGURE 1-8 When properly restrained and counterweighted, the subject is requested to slowly move forward in the direction of flexion of the lumbar spine. While the subject moves forward, the therapist should watch the round pad located behind the pelvis; this pad is free to rotate around its own axis, but should not rotate; any movement of this pad indicates that the pelvis is also moving. The subject should slowly move forward as long as there is no movement of the pad; but should stop if the pad starts to rotate.

True range of isolated lumbar-spinal movement is established by the range that is produced with no movement of the pelvic pad. Having determined the limit of forwards movement, the large goniometer (angle detector) tells the therapist the range of isolated spinal movement.

When a subject is properly restrained in the machine, the relationship of the pelvis to the pelvic-restraint pad becomes identical to the relationship of two gears locked together by their teeth; when either one of such a pair of gears rotates, then the other gear must also rotate. Exactly the same thing occurs in this machine; if the pelvis moves, then the pelvic-restraint pad must rotate around its own axis; movement of the pad that can be clearly seen. But if the pad does not move, you can be sure that the pelvis is not moving.

FIGURE 1-9 With the subject relaxed in the forward position, the computer monitor will show a bar-graph of torque; moving into this position compresses tissue in the front and stretches tissue in the rear of the torso, and this stored energy will produce torque in the direction of extension of the spine.

If not measured and considered, this nonmuscular torque will produce a significant overstatement of true strength in that position.

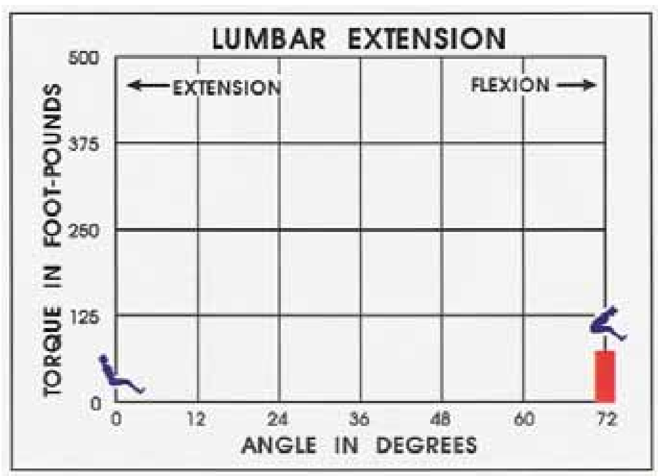


FIGURE 1-10 The bar-graph displayed on the monitor indicates the level of nonmuscular torque produced in that position. A large man, totally relaxed in the fully-flexed position, may produce more than 300 foot-pounds of nonmuscular torque. Torque that is not produced by the force of muscular contraction, but will overstate the true level of strength to an enormous degree.

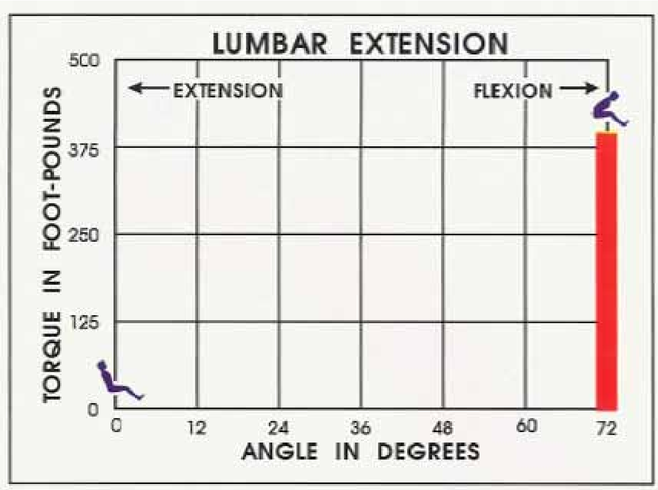


FIGURE 1-11 Having measured and recorded nonmuscular torque while relaxed, the subject should then gradually produce muscular force in the direction of extension of the lumbar spine. As the level of effort is increased, the monitor shows a rising bar-graph of torque. Having reached a maximum level of effort, the subject should maintain that level for approximately two seconds, and then slowly relax. Muscular force should be increased and reduced slowly, without jerking.

The maximum level of measured torque is functional strength in that position. When nonmuscular torque is subtracted, the remainder is the true level of muscular strength: torque actually produced by the force of muscular contraction, Net Muscular Torque, NMT, muscular strength unbiased by any source of nonmuscular torque.

With static testing, the artifacts inherent with all dynamic testing procedures are avoided.

All dynamic procedures produce error in test results from several unavoidable sources: impact forces, friction and stored energy (torque produced by stretching and compressing soft tissues). Without proper counterweighting, additional error is introduced by gravity.

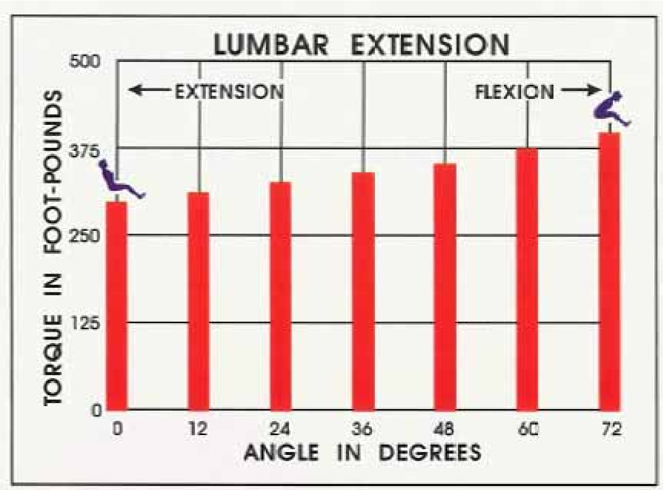


FIGURE 1-12 Having performed tests in several positions throughout a full range of movement, the monitor shows a bar-graph of torque in each position. A normal ratio of functional strength would show the highest level of torque in the flexed position and the lowest level in the extended position, with proportionate levels in intermediate positions.

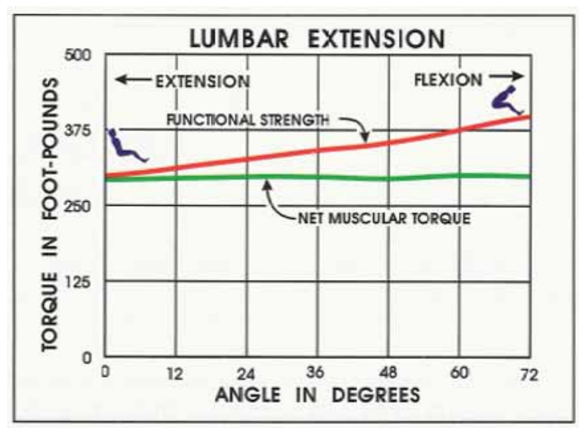


FIGURE 1-13 Based upon the torque measured in several positions, the computer will interpolate strength throughout the full range of movement; and the monitor will then show, and the printer will print, two distinct strength curves. The red curve show on the monitor is the full-range level of functional strength, expressed in foot-pounds (or Newton meters) of torque and correlated with positional measurements; while the green curve shows true muscular strength, NMT.

In addition to the two full-range strength curves, the printed report provides all of the raw data: both functional torque and NMT correlated with each tested position.

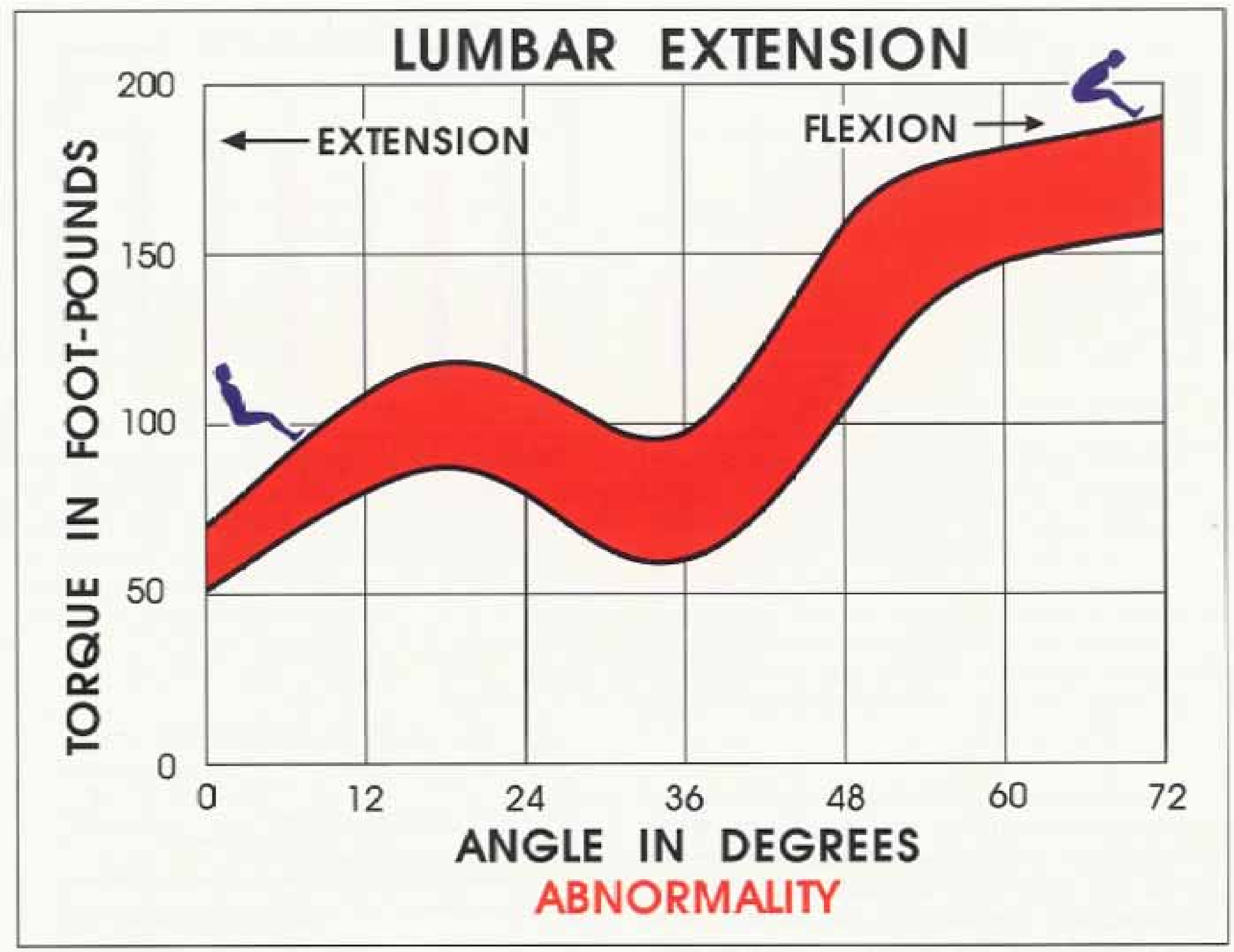


FIGURE 1-14 Two tests of functional strength performed by an abnormal subject. The top of the red area shows the level of fresh strength, while the bottom of the red area shows remaining strength after the subject was exercised. The red area between the two curves is fatigue from the exercise.

Both of these curves should have been straight lines. The dips in the midrange of movement should not have occurred, indicate abnormal function. The fact that the same abnormal shape was produced during both tests indicates valid test results. While the possible number of abnormal shapes is infinite, there is only one normal shape, a straight line; and significant variation from a straight line is an indication of abnormality.

This subject's strength was less than half of average for a normal male of his age and size: mid-thirties, five feet, ten inches, with a bodyweight of 160 pounds. With no history of spinal problems. A following series of lateral X-rays showed no abnormality, and a CT scan was also negative, but an MRI scan detected problems in two of the discs, and in two of the vertebral bodies.

A failure to produce consistent results in the shape of the curves during repeated tests is an indication of a noncooperative subject.

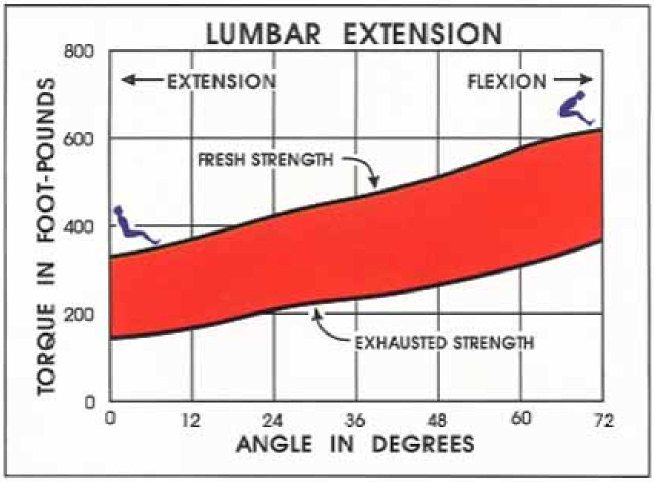


FIGURE 1-15 Fatigue characteristics are determined by a three-part procedure:

1 . . . A full-range test of fresh strength.

2 . . . Dynamic exercise to volitional fatigue.

3 . . . A test of remaining strength following the exercise.

The highest curve is the level of fresh strength, while the lower curve shows remaining strength following exercise. The red area between the curves is fatigue from the exercise. In this case showing a high level of fatigue produced by a brief session of submaximal exercise; indicating that this subject apparently has a high percentage of fast-twitch fibers in the muscle that extend the spine. Knowledge that is critical during rehabilitation since subjects with these characteristics sometimes cannot tolerate either frequent exercise or high-repetition exercise; will usually produce the best results from exercise for spinal muscles if worked only once each week, may lose strength if exercised more frequently. Subjects with a greater proportion of slow-twitch fibers in these muscles may produce better results during rehabilitation if exercised twice a week, or even three times each week.

Rehabilitative exercise must be based upon a clear understanding of fatigue characteristics on an individual basis. A schedule of exercise that was ideal for a subject with a high percentage of slow-twitch fibers might produce overtraining for a subject with different characteristics.

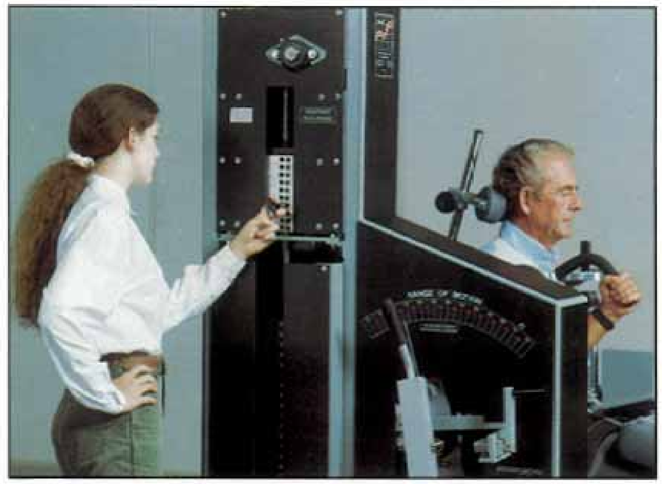


FIGURE 1-16 The lumbar-extension machine provides 391 levels of resistance for specific exercise; low enough for the weakest subject, or high enough for the strongest subject, but appropriate resistance for a subject with any level of strength. The level of resistance can be adjusted in increments of one foot-pound.

Range of movement for both testing and exercise can be limited to any desired part of a full-range movement, and the machine will not provide resistance outside the selected range of movement.

FIGURE 1-17 Both testing and exercise for the totally isolated muscles that rotate the torso are conducted in this machine; but since movement occurs in a lateral plane there is no need to counterweight the subject, torso-mass torque is not a factor. The muscles that rotate the torso are second in importance only to the muscles that extend the lumbar spine.

FIGURE 1-18 Clinicians using MedX evaluation and rehabilitation equipment can attend one of the six-day educational programs that are conducted twice each month. Directed by Michael Pollock, Ph.D., this school has been in operation by the Center for Exercise Science of the College of Medicine, University of Florida, Gainesville, for the last six years.

As an approved CME sponsor, the University of Florida College of Medicine has designated these educational programs for 37 hours of Category 1 of the Physician's Recognition Award of the American Medical Association.

As a part of each six-day program (Monday through the following Saturday), a day-long seminar is conducted on Friday; in addition to the students attending the ongoing class, these seminars are open to professionals from any branch of medicine who have an interest in the evaluation and rehabilitation of spinal pathology. Clinicians attending one of these Friday seminars receive 6 hours of Continuing Medical Education credit.

Directed by Vert Mooney, M.D., a second school was opened in San Diego in September, 1992, in cooperation with the University of California Department of Orthopaedics and Rehabilitation. A third school will be opened in Japan, and a fourth school in Europe.

For additional Information, or scheduled dates for classes and seminars in Florida, contact David Carpenter, Education & Research Annex, Sun Center, Suite 120, 101 SE Second Place, Gainesville, Florida 32601. Telephone: (904) 377-9600; Fax: (904) 377-9604.

For additional information, or scheduled dates for classes and seminars in California, contact Kerri Kazala, Educational Program for Musculoskeletal Evaluation, 4150 Regents Park Row, Suite 300, La Jolla, CA 92037. Telephone: (619) 625-0026; Fax: (619) 625-0206.

CHAPTER 2

RISK FACTORS

Controversy regarding identifiable risk factors related to spinal pathology has been ongoing for more than fifty years; with little in the way of agreement. While it should be obvious that a low level of strength is a risk factor for spinal injury, the Boeing study has been quoted as contrary evidence. But what that study actually demonstrated was the fact that the procedure used for testing strength could not achieve its intended purpose. Much of the functional testing performed during the last twenty years has been flawed in similar ways. Meaningful testing of spinal strength can be conducted only when all of the related factors are understood; and then only when the actual requirements for valid testing are provided. At the time the Boeing study was conducted, the requirements for valid testing were not established, and thus could not be applied.

FACTOR ONE: INADEQUATE STRUCTURAL STRENGTH

Apart from radiation, burns and a few other damage-causing factors, all injuries are a result of only two factors: force and inadequate structural strength. When an imposed force exceeds the coexisting level of structural strength, an injury will be produced; but a higher level of structural strength can withstand a higher level of force without resulting injury, thus the advantage of increased structural strength is beyond question.

Unfortunately, we cannot measure structural strength in a practical manner; structural strength can be determined only by tests carried to a point of destruction. However, there is an obvious, if unknown, relationship between functional strength and structural strength, and we can measure functional strength. It has been well documented that exercise increases the size and strength of the muscles, the tendons, the ligaments and the bones; thus increases in functional strength also increase structural strength, and reduce the chances of injury. The opposite situation being self evident, a low level of strength is a risk factor for spinal injury.

Meaningful testing procedures conducted with symptomatic patients prove this relationship beyond question: the typical patient with spinal pain demonstrates a level of strength far below average. Which was not surprising; but we were surprised to learn that even subjects with no history of spinal pain usually have a very low level of spinal strength. But low is a relative term; low compared to what?
Low compared to average strength? No, because average strength even for healthy subjects proved to be quite low.

Low compared to the potential strength of these muscles. Thousands of subjects have been tested for the isolated strength of their spinal muscles, so average untrained strength is now well established for both men and women. More than 3,000 of these subjects have been involved in research programs for increasing spinal strength; and, with few exceptions, the resulting increases in strength have been far greater than expected.

RESEARCH: During the last seven years, 45 different studies have been conducted at the University of Florida College of Medicine using MedX equipment for testing and exercise functions. These studies were conducted by a team of researchers headed by Dr. Michael Pollock and collectively involved a total of 3,339 subjects; together with a total of 18,540 functional tests and more than 100,000 exercise procedures.

Additional studies using MedX equipment have been conducted by other researchers in several locations in this country and abroad. In order to conform with the regulations required by the Japanese version of our FDA, clinical studies were performed in major hospitals in Japan. In July of 1991, a study was presented at an international symposium of physical therapists in England, showing the results produced by a group of paraplegic subjects who were exercised with MedX equipment.

Many studies performed during the last twenty years have clearly established the degree of results that can be expected when a previously-untrained subject is exposed to exercise; so we know what to expect. Most such studies involve the performance of three sets of the exercise during each of three weekly training sessions, with a brief rest between exercise sets; so a ten-week program would involve ninety exercises, with the expectation that the starting level of strength would be increased approximately 25 percent by the end of the program.

But those are the results expected from exercise for the quadriceps muscles, or almost any other muscle. When isolated exercise for the muscles that extend the lumbar spine is performed on a regular basis, the results are usually far greater: in the extended position, strength increases of 100 percent are below average, and increases of several hundred percent are common.

Since no other muscle in the body demonstrates anything close to an equal degree of potential strength increase, it appears we are dealing with muscles in a state of disuse atrophy; a conclusion that has been proven by long-range research with thousands of subjects.

FREQUENCY OF EXERCISE

While we were surprised by the potential for strength increases shown by spinal muscles, we were even more surprised to find that very little is required in the way of exercise to produce such great increases in strength. Provided only that the exercise is specific. The results shown by the following three examples demonstrate both of these points: magnitude of increases in spinal strength, and the relationship between the strength increases and the amount of exercise that was required.

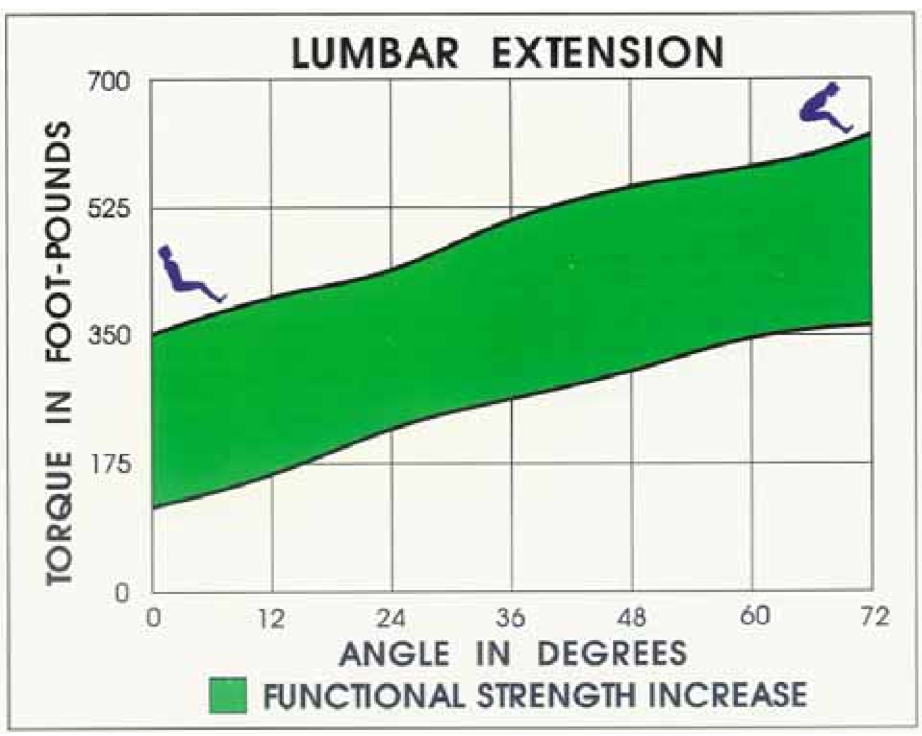


FIGURE 2-1 A healthy male subject with no history of lower-back pain, in his mid-twenties with a height of 6 feet and a lean bodyweight of 200 pounds.

The lowest curve shows fresh strength of the isolated lumbar-extension muscles measured during an initial test of functional strength. The higher curve shows strength ten weeks later. The green area between the two curves represents increases in functional strength produced by only ten weeks of isolated exercise. With only one exercise each week during that period.

Strength in the flexed position increased 68 percent, while strength in the extended position increased 180 percent. Initially, this subject performed nine full-range movements against resistance of 200 foot-pounds; ten weeks later he performed nine repetitions with 400 foot-pounds; an increase in dynamic strength of 100 percent.

A total of only 10 exercises during a period when most exercise programs would have required 90 exercises. While it might appear that he would have done better if he had performed more exercise, it is probable that his results would have been better if he had performed even less exercise. This example presents the results that were produced by the subject that showed the lowest magnitude of strength increases in our first study group; all other subjects in this group produced better results, and all of the other subjects were exercised only once every two weeks.

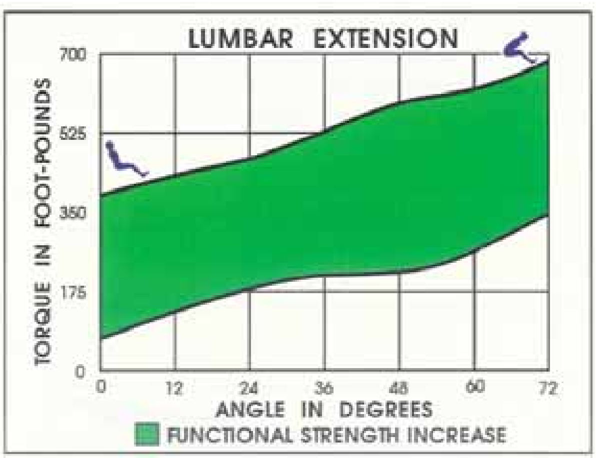


FIGURE 2-2 Another member of the first research group. The subject was a healthy male with a twenty-year history of hard exercise, a man that would be expected to be far above average strength at the start; mid-thirties, five feet, nine inches with a muscular bodyweight of 190 pounds. In a period of five months and eight days, he increased his functional strength in the flexed position more than 101 percent, in the extended position by 450 percent; as a consequence of isolated exercise for the spinal muscles only once every fourteen days during that period. His dynamic strength increased from an initial 13 repetitions against resistance of 150 foot-pounds to a later performance of 8 repetitions with resistance of 800 foot-pounds.

DISUSE ATROPHY

The results produced by both of these subjects make it obvious that they started at a low level of strength resulting from a state of chronic disuse atrophy; their magnitudes of strength increase can apparently be justified in no other manner. Atrophy that continued in spite of a long history of previous exercise in both cases; atrophy that was corrected only after they were exposed to specific, isolated exercise.

Subsequent research has clearly demonstrated that most of the exercises performed for the purpose of increasing spinal strength are worthless for their intended purpose; may strengthen the muscles of the hips and thighs, while leaving the lumbar muscles in a continuing state of atrophied weakness.

RESEARCH: Four large groups of random subjects, both male and female, were studied for twelve weeks. All subjects were tested repeatedly for the isolated strength of the muscles that extend the lumbar spine before the start of the exercise program, and were tested again in an identical manner at the end of the twelve-week period.

During the exercise program, all subjects in three of the groups were exercised once each week; one group was exercised using a MedX Lumbar-extension machine . . . a second group exercised with a Nautilus Lower-back machine ... a third group exercised with a Cybex Lower-back machine ...and the fourth group performed no exercise, serving as a control group.

As expected, the control group showed no change; but the Nautilus and Cybex groups also showed no change... while the MedX group produced very significant increases in spinal strength.

The Nautilus Lower-back machine was invented by me and the patent was issued in my name; to the best of our knowledge it was the first machine ever built for the express purpose of exercising the lumbar-extension muscles. Subsequently it has been copied by a number of other companies producing exercise machines, and several slightly different variations of this machine are now being marketed.

When I designed that machine I clearly understood that it provided exercise for both the hip and thigh muscles ... but I then believed that it also provided meaningful exercise for the lumbar extension muscles; an assumption that I now realize was wrong. The machine is misnamed, in fact a hip and thigh machine, provides meaningful exercise only for the muscles of the buttocks and rear of the thighs.

I founded Nautilus Sports/Medical Industries, Inc., in1970, and served as chairman until it was sold in June of 1986; selling controlling interest in the company in order to devote my full attention to the continued development of specific testing and exercise equipment for several critical areas of the body, with particular emphasis on the lumbar spine, the cervical spine and the knee. The project that eventually did lead to the development of safe, accurate, specific testing and exercise equipment was started more than twenty-two years ago while I was directing Nautilus; but was not successful until after I sold the company.

This clear statement of fact must not be misunderstood as an indictment of Nautilus or any other product of that company; we all make mistakes, and the misnamed lower-back machine was one of my mistakes, a mistake now being copied by several companies in the field of exercise.

NOTE: An associate raised the possibility of another explanation for the initial low level of strength in the spinal muscles of the last subject mentioned above, (Figure 2-2). Rather than disuse atrophy, he might have been showing the results of overuse atrophy.

This subject apparently has a very high percentage of fast-twitch fibers in his lumbar muscles, and performed regular, heavy exercise for twenty years prior to his first test of spinal strength. Such fast-twitch subjects sometimes cannot tolerate frequent exercise. But, overuse or disuse, his following strength increases clearly established his initial state of spinal atrophy.

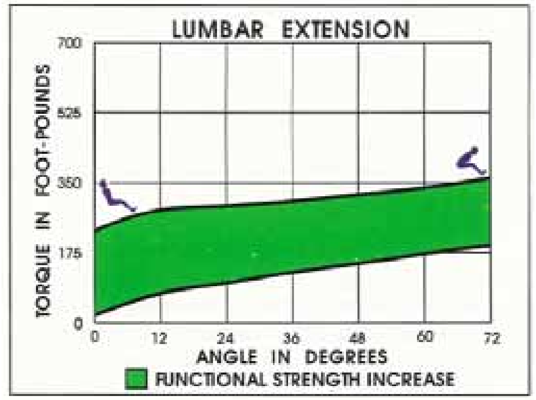


FIGURE 2-3 A third subject from the first group; a male with a history of spinal surgery performed about ten years prior to the date of the first test shown on this chart. This subject increased his isolated lumbar-extension strength by more than 93 percent in the flexed position, and by 877 percent in the extended position, in a period of 27 weeks. Strength increases which indicate that he started in an atrophied condition.

All three of these subjects were involved in regular exercise programs for a period of several years immediately prior to their initial tests; would be expected to be stronger than average; but all were below average strength. But when these subjects were first tested, the average level of strength for these muscles had not been established; so we had no basis for comparison at the time of their initial tests.

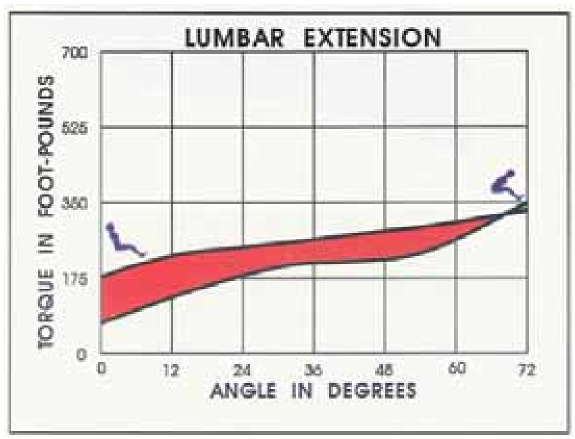


FIGURE 2-4 Initial strength compared to average strength for a fast-twitch subject in our first study group, Figure 2-2. The red area represents the difference between his starting strength (below average) and

and average strength. (Five months later, he was 101 percent stronger in the flexed position and 450 percent stronger in the extended position. Was then far above average strength.

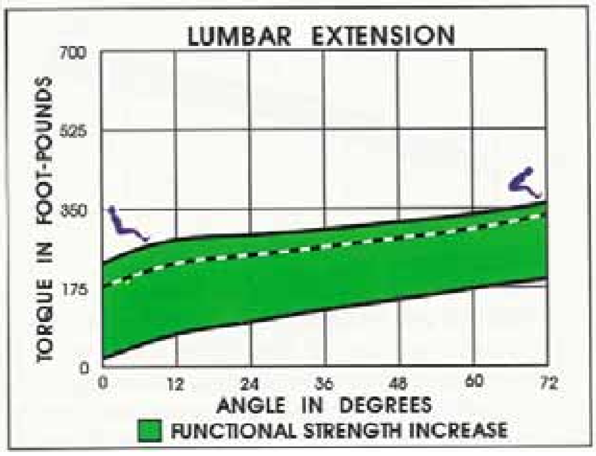


FIGURE 2-5 Initial strength compared to strength following 27 weeks of specific exercise for a subject mentioned earlier, Figure 2-3 ... with the addition of a curve showing average strength. This 24W subject was not far above average strength even at the end of the training period; but he started at a very low level of strength compared to average. His relatively low level of final strength, compared to the other two subjects, was a result of the fact that he appears to have a high percentage of slow-twitch fibers in these muscles; a fiber type that provides great muscular endurance but precludes a high level of strength.

Six years later, In the meantime having seen similar results with thousands of subjects, the conclusion is unavoidable: even normal, pain free individuals will usually show a very low level of spinal strength when initially tested. . . but most will produce rapid gains in spinal strength when provided with specific exercise.

FACTOR TWO: MUSCULAR FIBER-TYPE

A second risk factor related to spinal pathology is a result of differences in fiber type. A majority of a random group of subjects will show a mixture of fiber types in these muscles. Fiber types that can be identified by a three-part procedure for determining fatigue characteristics on an individual basis. Tested for their level of fresh strength, then exercised against an appropriate level of resistance, and immediately retested for their remaining level of strength, a comparison of fresh strength (pre-exercise) to remaining strength (post-exercise) will provide a clear picture of the fatigue characteristics on an individual basis.

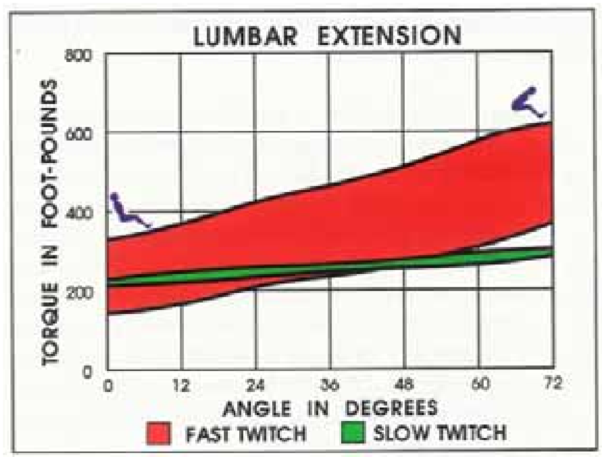


FIGURE 2-6 A comparison of the fatigue characteristics of two of the subjects mentioned earlier, Figures 2-2 and 2-3. The red areas on this chart show fatigue resulting from exercise performed by a fast-twitch subject, while the green area shows a gain in strength following an identical procedure performed by a slow-twitch subject. Both subjects were tested for fresh strength, were then exercised briefly with a low level of resistance, and were immediately retested for remaining strength following the exercise. But even following a brief, light session of exercise, the fast-twitch subject lost a very large part of his fresh strength, while the slow-twitch subject was stronger following the exercise than he was before the exercise.

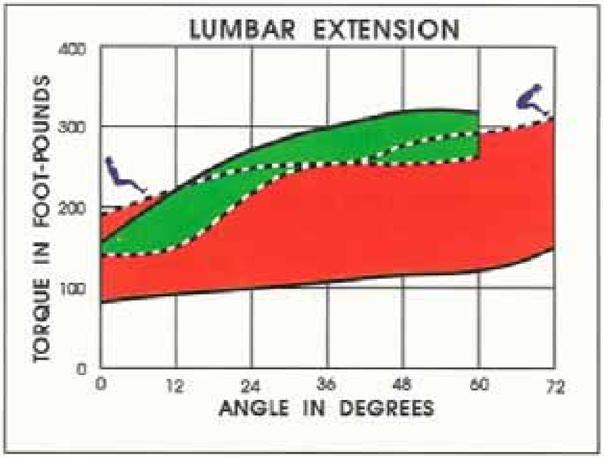


FIGURE 2-7 Testing for fatigue characteristics (muscular fiber type) provides vital information during rehabilitation. The schedule of exercise must be based on careful consideration of this factor.

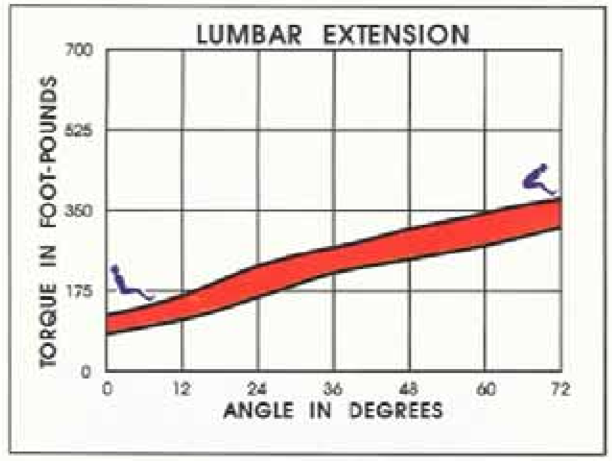


FIGURE 2-8 Fatigue characteristics of a subject with a usual mixture of fiber types. The red area represents the loss of fresh strength following an exercise continued to failure; nine repetitions against resistance of 200 foot-pounds. An overall loss of fresh strength of approximately 20 percent.

Figure 2-7 provides a graphic example of individual differences in response to exercise produced by variation in muscular fiber type: these two subjects were tested for fresh strength, were then exercised to volitional fatigue, and were immediately retested for remaining strength after the exercise. Tested and exercised in an identical fashion, a majority of a random group of subjects will show a loss of approximately 20 percent of fresh strength. But these two subjects produced different responses. One showed a fast-twitch response to exercise, while the other produced a slow-twitch response.

The green area shows gains in fresh strength with the slow-twitch subject; while the red areas show losses of fresh strength by the fast-twitch subject. The curves of fresh strength are dotted, while exhausted curves of strength are solid. The fast-twitch subject lost 58 percent of his fresh strength as a result of brief exercise; while the slow-twitch subject was 23.5 percent stronger following the exercise.

In the midrange of movement, the levels of fresh strength were identical, 254 foot-pounds of torque; but during the tests of exhausted strength, the slow-twitch subject was 179 percent stronger in the same position, 299 compared to only 107 foot-pounds. These differences are critical, but can be easily determined by a simple testing procedure. An ideal exercise schedule for one of these subjects would probably be intolerable f for the other.

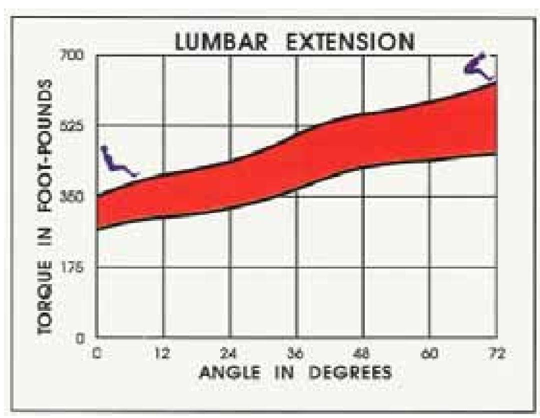


FIGURE 2-9 Fatigue characteristics of the same subject, Figure 2-8, at a much higher level of strength. In this case, he failed after nine repetitions with 400 foot-pounds, twice as much resistance as used in the previous test; and then showed an overall loss of strength of approximately 25 percent.

While there was a slight change in the fatigue characteristics, from an initial loss of 20 percent of fresh strength to a later loss of 25 percent, these results do not indicated significant change in apparent fiber type. The key word in that last sentence being apparent; muscular fiber type does not change as a result of strength increases, but will sometimes appear to change.

Muscular atrophy, both disuse atrophy and overuse atrophy, is largely selective on the basis of fiber type; fast-twitch fibers atrophy faster and to a greater extent than slow-twitch fibers. The fast-twitch subject mentioned earlier, Figure 2-2, when first tested, appeared to have a usual mixture of fiber types; but as his strength increased, his fiber type appeared to change. At a level of strength far above his initial level, he showed the characteristics of a subject with a very high percentage of fast-twitch fibers.

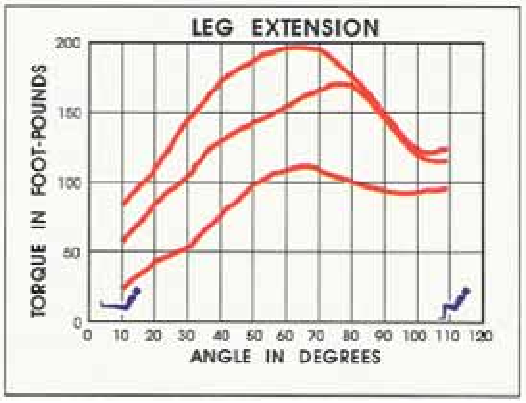


FIGURE 2-10 Selective atrophy of quadriceps muscles. The highest curve represents fresh strength of a normal leg, the lowest curve is fresh strength of an injured leg, and the middle curve is fresh strength of the same injured leg following a period of rehabilitation.

Exercised to failure after ten repetitions, the injured leg lost only 11 percent of fresh strength; a slow-twitch response.

Exercised in the same manner, the partially rehabilitated leg lost 25 percent of fresh strength; a usual fiber-type response.

As strength increased, fiber type appeared to change. When fully rehabilitated, the injured leg showed a fast-twitch response to exercise, a loss of 44 percent of fresh strength following exercise.

The risk associated with a high percentage of fast-twitch fibers is clear: while such subjects may be stronger than expected, based upon sex, age and size, they have little in the way of muscular endurance. Will become exhausted even from very brief exposure to light exercise.

A high percentage of slow-twitch fibers in the muscles that extend the lumbar spine does not preclude injury, but it appears that such subjects have an advantage not shared with fast-twitch subjects. While final figures are not yet available, an initial examination of the testing results produced by thousands of symptomatic subjects during rehabilitation indicates that fast-twitch subjects represent a disproportionately high percentage of a random pathological population, while slow-twitch subjects are less common than they would be in a population of normal subjects.

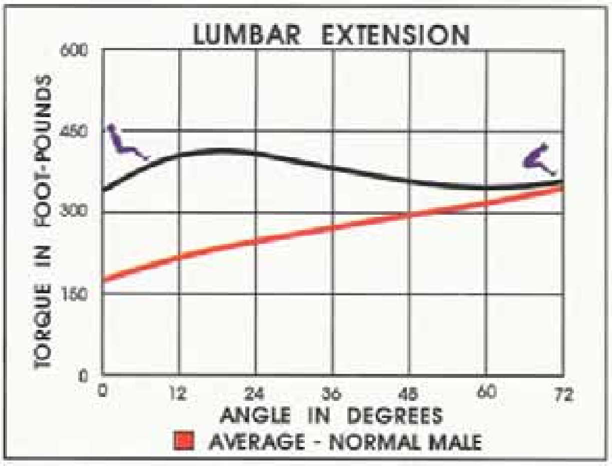
FACTOR THREE: RANGE OF MOTION

Average, normal range of motion has been established for both men and women, and a significant loss of normal range may be an indication of spinal pathology. While there is variation on an individual basis, full range movement of the lumbar spine (flexion/extension) is 72 degrees with an average, normal subject; with no pelvic movement. Normal torso rotation, with no movement of the pelvis, is 120 degrees; 60 degrees to the right, and 60 degrees to the left of a neutral (straight-forward) position.

Standards for judging pathology based upon a loss of normal range of movement have not been established; but many symptomatic subjects show a marked decrease in normal ranges of movement, and some patients produce large increases in range of movement during the course of rehabilitation.

FACTOR FOUR: SPECIFIC RESPONSE TO EXERCISE

An additional risk factor for spinal pathology is a result of a specific (Type S) response to limited range exercise. Some subjects produce limited-range strength gains when exercised with limited-range movements; may produce enormous gains in strength within the worked range of movement while showing no change in strength within the unworked range; may even produce gains in the worked range while showing losses in strength in the unworked range.



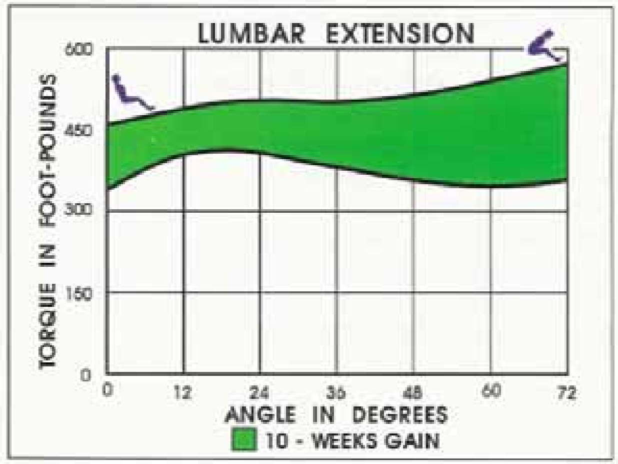


FIGURE 2-11 A disproportionate strength curve produced by limited-range work. Strength in the flexed position, which is normally the strongest position, was average for an untrained man; while strength in and near full extension, normally the weakest positions, was far above average. The red curve shows average strength for a normal, untrained man.

A proportionate curve of functional strength, at any level of strength, should be a straight line; any meaningful deviation from a straight line is an indication of abnormality. The subject illustrated above produced this abnormal strength curve as a consequence of thirty-six years of competitive water ski activity; a sport that exposed his spinal muscles to a heavy workload near full extension. Work that produced an abnormally high level of strength in the extended part of the range, while doing nothing to increase his strength near the flexed position. A specific result produced by limited-range work.

Dr. Michael Fulton has served as team physician for several international teams of water skiers during the last few years; which provided the opportunity to conduct tests on a relatively large number of people, both male and female, that have been exposed to such limited-range work for long periods, and the above example is typical of the strength curves shown by most such subjects: very strong near full extension, but average strength near the flexed position.

FIGURE 2-12 Strength increases produced by the subject shown in Figure 2-11 during a period of ten weeks; during which period he performed a total of only five testing and exercise procedures, at intervals of approximately two weeks.

After thirty-six years of water-ski activity, his strength in the flexed position was still only average for an untrained man; but five exercises performed during a period of ten weeks increased his strength in the flexed position by 60 percent, while increasing strength in full extension by 33 percent, and increasing strength 20 degrees away from full extension, his initial position of peak strength, by 22 percent. His dynamic strength increased by 60 percent during that same period; from an initial performance of fifteen full-range movements against resistance of 175 foot-pounds, to a later performance of fifteen repetitions with 280 foot-pounds.

Even then his strength in the flexed position was not in proportion to his strength in full extension; a few more weeks of continued training with specific exercise would probably have produced a full-range, proportionate, strength curve, but his work schedule made additional exercise impossible.

Because many subjects show such a specific response to limited-range work, and since most exercises provide little or no work for the spinal muscles in a position of full extension, even normal subjects will usually show a disproportionately low level of strength near full extension when initially tested. Which explains why most subjects produce better results in the extended position than they do in the flexed position when provided with specific exercise: while their spinal muscles are weak from disuse atrophy in every position, the initial state of atrophy is usually worse in the extended position.

The unique nature of the muscles that extend the lumbar spine is reinforced by the response of other muscles in the same area of the body; the torso do not have an equal potential for experience with thousands of normal research subjects, together with lower-back-pain patients, has clearly shown that the muscles that rotate strength increases. Specific exercises for the torso-rotational muscles will increase the strength of these muscles to a marked degree ... but not to the degree shown by the extension muscles.

Taken together, the risk factors for spinal injury covered by this chapter go a long way in the direction of explaining why injury is so common in the lumbar spine; injury that might have been prevented in many cases by specific exercise, and that can be rehabilitated in most cases without surgery.

1 . . . Low levels of functional and structural strength resulting from disuse atrophy.

2 ... Fast-twitch muscular fiber-type.

3 ... Limited range of movement.

4 ... Specific response to limited-range work.

All four of these factors can be identified by MedX testing... and three of them can be improved by specific exercise. While we cannot change muscular fiber type, we can increase both functional and structural strength regard less of fiber type, and doing so will reduce the risk of Injury.

CHAPTER 3

MISLEADING TESTING PROCEDURES

Four distinct risk factors related to spinal pathology **have now been established; factors that can be identified by meaningful testing procedures . . . but this requires an understanding of the differences between tests that are meaningful and tests that are misleading.**

Space devoted to things that do not work is not wasted ... on the contrary, learning is largely a process of elimination; until these failures are carefully examined and understood, our efforts may continue in the wrong direction.

The most common mistake has been the use of dynamic testing procedures. Which was sometimes rationalized on the grounds that dynamic strength is more relevant than static strength. But both static and dynamic tests of strength are actually tests of the same factor, an indirect measurement of the force of muscular contraction.

ERROR FROM PEAK TORQUE

Confusion has resulted from attempts to monitor changes in strength by measuring peak torque; but even when measured accurately, changes in peak torque do not provide a meaningful picture of gains (or losses) in strength. The following example demonstrates this point clearly.

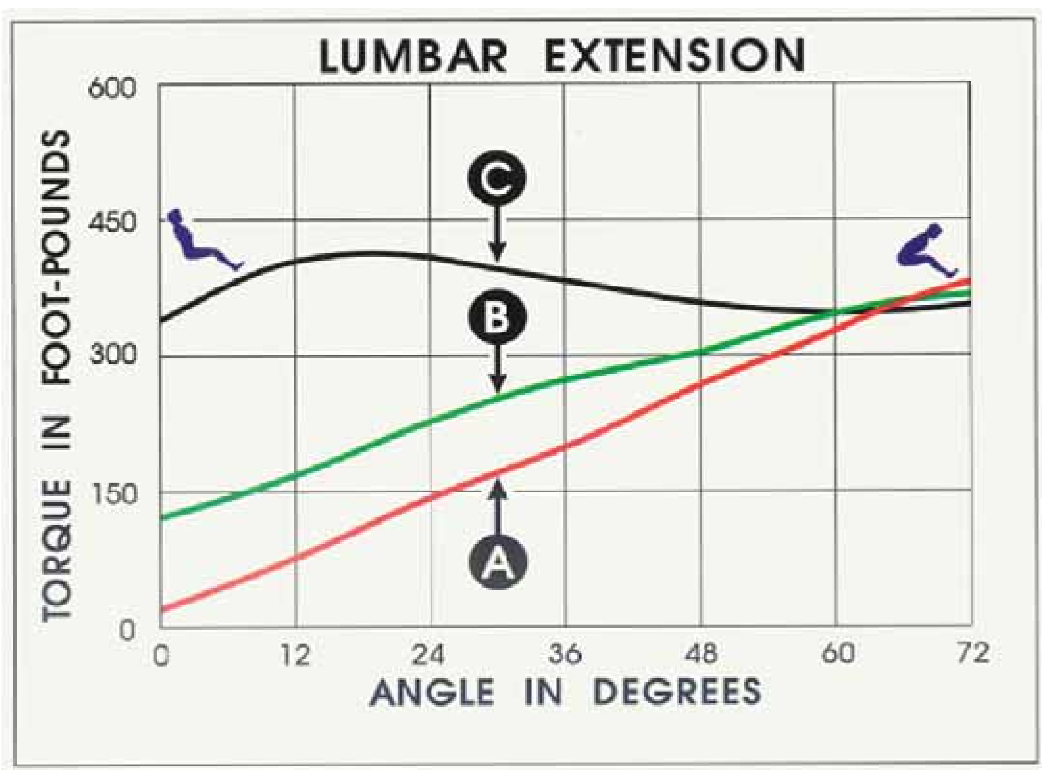


FIGURE 3-1 Comparison of three male subjects with the same level of strength in the flexed position, the usual position of peak torque; in the flexed position, their strength levels varied by less than three percent.

But very significant differences in strength existed in all other positions; subject A produced only 26 foot-pounds of torque in the extended position .. . B was nearly five times that strong in the same position, 125 foot-pounds ... and C was much stronger than the other two, 343 foot-pounds.

Following their initial strength tests, these subjects were exercised with what we considered an appropriate level of resistance; based upon their tested levels of fresh strength. In one case we guessed right, but in two cases our estimates were wrong. Subject B was given 200 foot-pounds of resistance for the exercise, and performed nine repetitions; so our estimate was correct in that case.

Subject A, given only 150 foot-pounds of resistance, could not perform even one full-range movement; was forced to stop before reaching the midrange of movement. Weakness beyond that point prevented additional movement against the level of resistance provided. When the resistance was reduced to only 100 foot-pounds, he was able to produce full-range movement; but even with this lower level of resistance, movement in the extended part of the range could be produced only with great difficulty.

Subject C, given 175 foot-pounds of resistance, performed fifteen full-range movements; the resistance was too low. With 225 foot-pounds he would probably have performed nine or ten repetitions.

Trying to evaluate these three subjects by comparing their peak levels of torque, particularly if torque in the flexed position was compared, would be misleading. Judging their later progress by the change in peak torque would produce an understatement of their actual gains in strength. For any meaningful evaluation of spinal function, torque must be measured throughout a full range of possible movement.

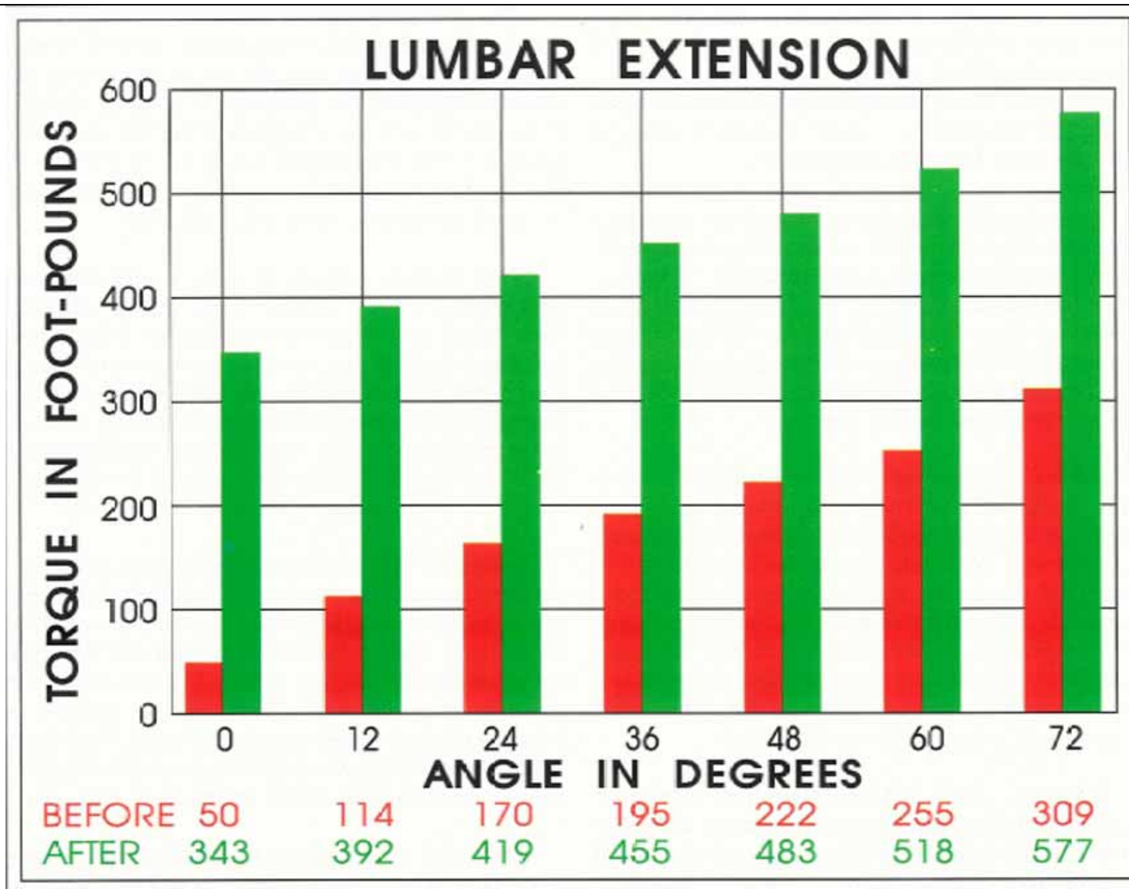
Subject C, in the fully extended position, was more than thirteen times as strong as A (343 compared to only 26 foot-pounds); bringing subject A up to the same level in that position would require a gain in strength of 1,219 percent. But is such an increase even possible? In our first study group of male subjects (all members of our research staff), two of these men increased their initial levels of strength in the fully-extended position to an even greater degree.

The potential for strength increases is largely determined by the initial level of strength; and when starting with the very low level shown by subject A in the extended position, the potential for gains in strength is enormous. But increasing his strength in the flexed position to the same degree would not be possible; in the flexed position, an increase of 80 percent is probably as much as could be reasonably expected.

Two of these subjects, B and C, were exercised and retested over a period of ten weeks following their initial tests shown above. Subject B increased his initial level of peak torque by 68 percent during that period; but evaluating his improvement by the change in peak strength would be misleading, because his strength in the fully extended position increased by 180 percent during the same period. And his full-range, dynamic strength increased 100 percent.

Subject C was initially strongest twenty degrees forward from full extension, and during the following ten weeks his strength in that position increased by 22 percent. But in the flexed position his strength increased by 60 percent, with a 33 percent gain in the fully-extended position; and with an increase of 60 percent in full-range, dynamic strength. With both subjects, their changes in peak torque were misleading; did not indicate their actual increases in strength.

Subject A was a physical therapist from Philadelphia, and was tested during a medical seminar in Florida, so was not available for later exercise and testing. A healthy male in his mid twenties, about six feet with a lean bodyweight of approximately 200 pounds, he had been exercising on a Cybex lowerback machine for several years prior to the test shown above; exercise that obviously did little or nothing to increase the strength of his lower-hack muscles. Given his very low level of strength in the extended part of a full range of movement, it is almost certain that a few weeks of specific exercise would have increased his peak torque by at least 60 percent, while increasing strength in the fully-extended position by more than 1,000 percent. His full-range dynamic strength would probably have increased more than 300 percent.



RESEARCH: During a six-month study, the average Increase In peak torque produced by our first group of normal male subjects was 87 percent ... but their average increase in a position of full extension of the lumbar spine was much greater ... while the average overall change (area under the curve) was an increase of 142 percent.

A later study with a larger group of subjects, both male and female, was continued for a period of 20 weeks ... with testing performed at the start, after 12 weeks, and after 20 weeks. Having produced large gains in spinal strength during the first 12 weeks of the study, during the last 8 weeks the average increase in peak torque was only one percent; but during that same period, strength in the extended position increased an average of 31 percent . . . very significant gains in strength that would have been overlooked If gains were judged by the change in peak torque.

A FAULTY ASSUMPTION

It has been assumed, until recently, that tested functional torque is a result of the force of muscular contraction . . . and thus it was assumed that changes in functional strength were in proportion to changes in the strength of the involved muscles. But both assumptions are invalid.

Muscular strength is a result of only one factor, the force of muscular contraction. But tested torque is a result of four factors; part of the torque may (or may not) be a result of muscular force, but it is not the only factor. Torque is also produced by the effect of gravity on the mass of the involved body parts, by stored energy, and by muscular friction if a dynamic test is involved. Until all of these factors are measured and considered in relation to tested torque, the results will be misleading at best.

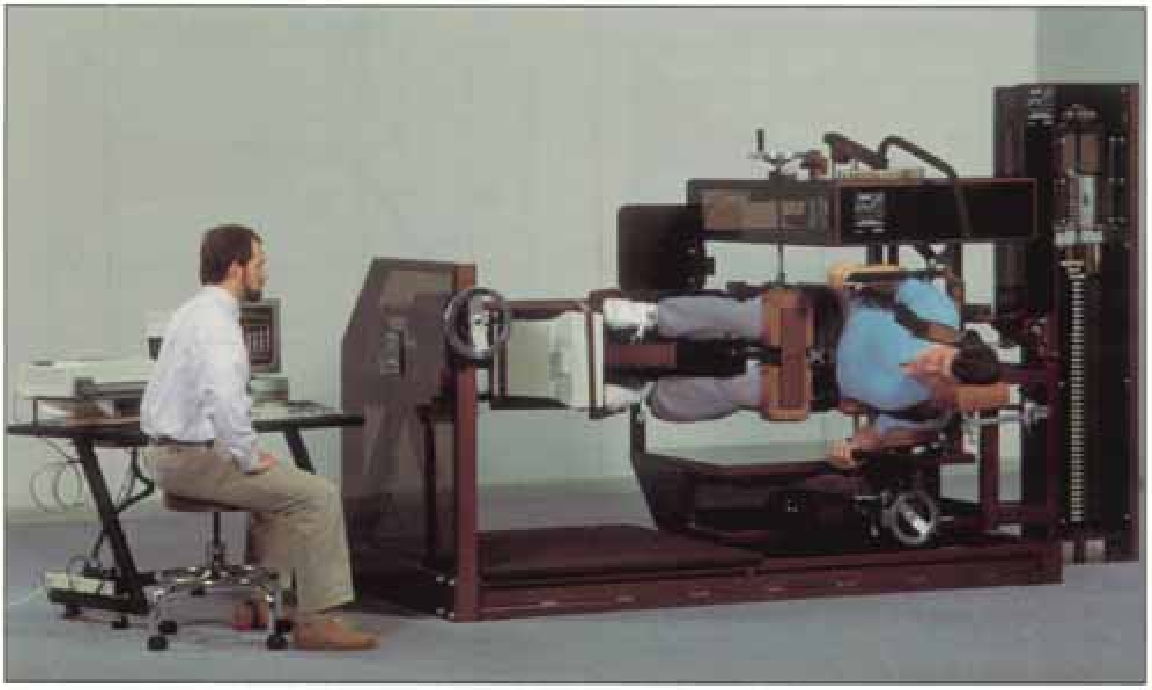


FIGURE 3-2 Primarily intended for clinical research, this version of the lumbar-extension machine provides both testing and exercise when rotated into a lateral position as illustrated above; a position which removes the usual effects of gravity, so that torque from the subject's torso mass is not involved. Static tests performed in this manner are biased only by stored-energy torque; but in tests of lumbar strength, stored-energy torque is a very significant factor.

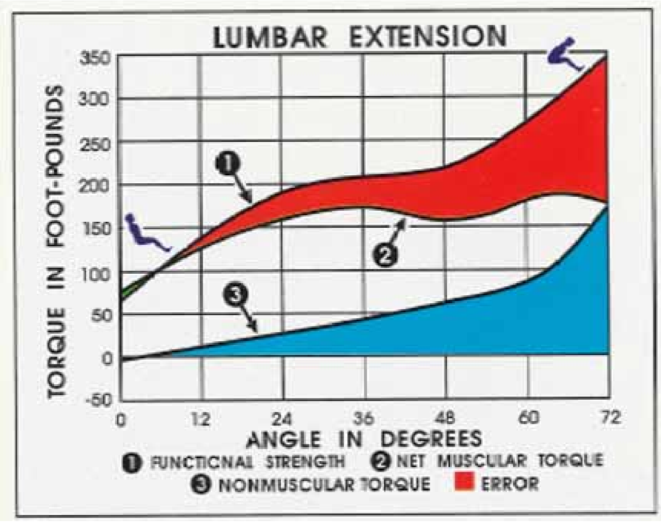
Moving into the flexed position of the lumbar spine stores energy by compressing tissues in the front and stretching tissues in the rear of the torso; this stored energy will then produce force in the direction of extension, and the resulting torque will be shown by the monitor as a bar graph, while the computer will record the exact level of torque. If a seated position produces so much stored-energy torque, then why not test upright like the B200 or the Cybex? Because unwanted pelvic movement cannot be prevented in a standing position; so tests in that position are misleading, regardless of how they are conducted.

If the fresh corpse of a large, dead man was restrained in this machine in the lateral position shown above, with the body pulled into a position of full flexion of the lumbar spine, then the output of torque might exceed 300 foot-pounds; torque that obviously would not be a result of muscular contraction.

Tested in an upright position, without proper counterweighting, where the effects of torso-mass torque would also be involved, the results would be more misleading.

With a living subject, tested in any dynamic fashion, where the effects of friction and impact forces would be added, the test results would have no relationship with true strength.

These nonmuscular factors are not minor considerations that can be safely ignored during testing procedures. For meaningful test results, true muscular strength must be measured: the torque actually produced by the forces of muscular contraction, Net Muscular Torque, NMT. In order to determine NMT, all nonmuscular-torque factors must be measured and considered in relation to the levels of tested torque.



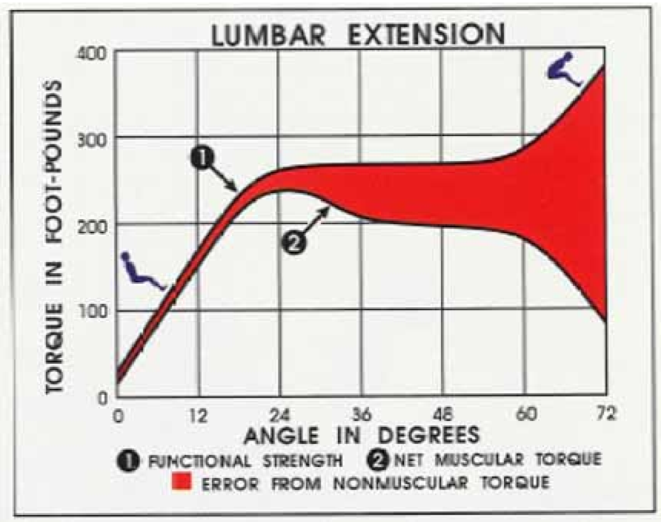


FIGURE 3-3 The results produced by a test of isolated lumbar-extension strength, functional strength, compared to a test of true muscular strength, NMT. The highest curve shows functional strength, the middle curve shows true strength, NMT, and the lowest curve shows the torque produced by stored energy. The red area between the highest curve and the middle curve shows the error introduced if stored energy was not considered; while the lower, blue area shows torque resulting from stored energy. A failure to consider stored energy in this case would lead to an overstatement of true strength in the flexed position of nearly 100 percent, with a slight understatement of true strength in the extended position.

These results were produced by a member of our initial group of test subjects; five months later, following a program of specific exercise, he showed a gain in functional strength of 101 percent in the flexed position, together with a gain of 450 percent in the extended position. But his true gains in strength, changes in NMT, were 196 percent in the flexed position and 440 percent in the extended position. With symptomatic subjects, the error from nonmuscular torque may be even worse; as demonstrated by the following example.

FIGURE 3-4 A patient with a twelve-year history of chronic lower-back pain; a big man, six feet, four inches, with a bodyweight of 260 pounds. The highest curve shows the level of fresh functional strength; while the lower curve shows true muscular strength, NMT. The red area between the curves represents error in test results produced by stored energy. Following eleven weeks of rehabilitation, his functional strength in the flexed position was T percent higher than the level shown here ... but his true increase in that position was more than 353 percent. Evaluation during rehabilitation must be based upon changes in true strength, NMT; changes in functional strength are grossly misleading.

It would probably be too much to expect most people to perform calculations in an effort to measure true strength; so the measurements of nonmuscular torque must be performed by the testing equipment, and the calculations done by the computer, with the test results presented to the therapist as an accurate measurement of true strength, unbiased by any non muscular factor . . . strength produced only by the forces of muscular contraction.

IMPACT FORCES

In addition to misleading test results, any dynamic mode of testing unavoidably exposes the subject to high levels of impact force; a subject may produce only 100 pounds of force but be exposed to 500 pounds of force, or more.

With static testing, the force actually produced is almost exactly the same as the force imposed upon the subject. Some low level of impact force is unavoidable even in static tests; but if static tests are properly performed, the imposed force should not be more than one or two percent above the force produced by the subject. During rehabilitation, dealing as you usually are with an already damaged joint, the last thing you should be doing is imposing high levels of unrequired force during either testing or exercise ... on the contrary, force should be as low as possible consistent with the requirements; If not, you may determine the limits of structural strength by producing an injury.

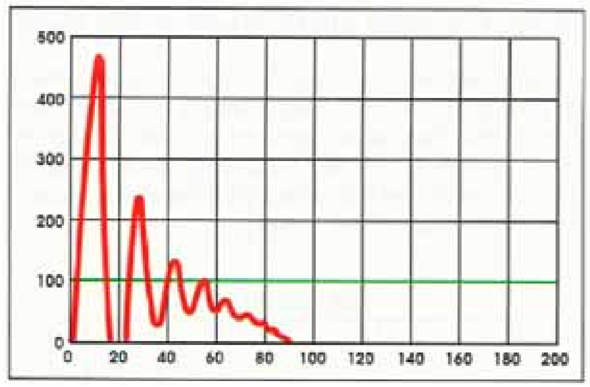


FIGURE 3-6 But when a known torque was imposed upon a Cybex isokinetic machine, and permitted to move through a range of 90 degrees, this is the actual result. This is not a measurement of torque, instead shows the results of impact force produced by the rapidly changing speed of the machine. This machine does not, as is claimed, provide a constant speed of movement; instead, the speed varies by several hundred percent, from far below the selected speed to far above the selected speed; with the resulting impact forces recorded here.

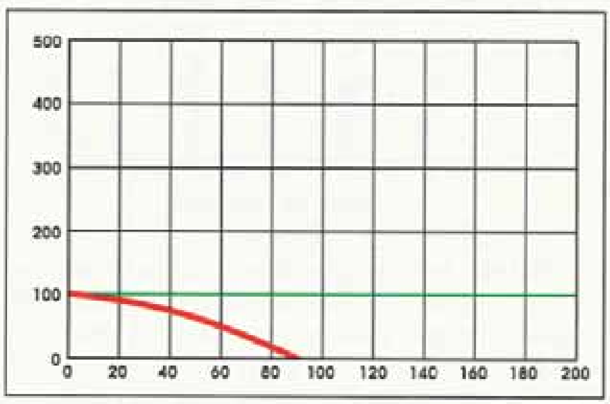


FIGURE 3-5 Using an isokinetic machine (Cybex), if a known level of 100 foot-pounds of torque was imposed, and if the machine moved through a range of 90 degrees, this is the exact curve of torquethat should be recorded.

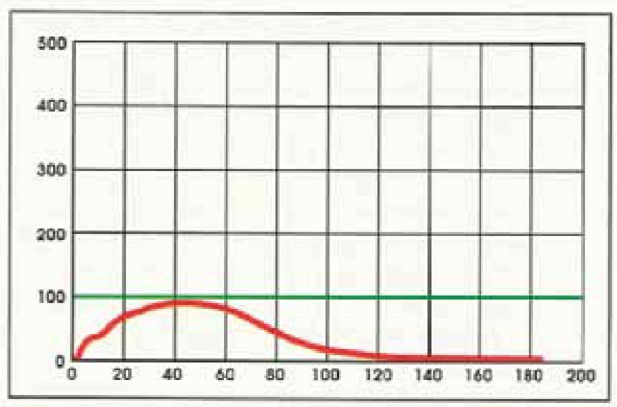


FIGURE 3-7 Electronic damping of the force measurements distorts the actual test result until it looks like the curve shown here; with no relationship to either what should have happened (Figure 3-5) or what did happen (Figure 3-6), and the actual range of 90 degrees was changed to an indicated range of 183 degrees. These examples were produced by tests with a Cybex isokinetic machine; and several studies have been published in a number of scientific journals during the last few years showing similar results.

Following examples clearly illustrate several other problems produced by dynamic test procedures.

ERROR FROM MUSCULAR FRICTION

Another source of error in all dynamic tests is produced by muscular friction; an important factor that has been ignored or overlooked by many people in this field. But If Ignored, the error introduced by friction makes it impossible to produce meaningful test results.

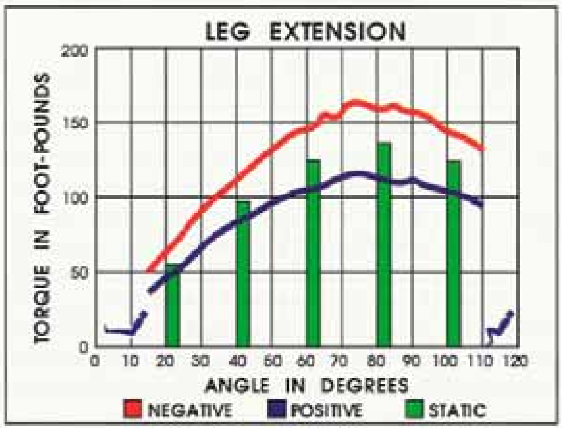


FIGURE 3-8 Results of a three-part procedure for testing fresh functional strength of the quadriceps muscles (leg extension). The bar-graphs represent static torque in several positions throughout the range of movement, while the highest curve is the coexisting level of eccentric (negative) strength, and the lowest curve shows concentric (positive) strength. Three simultaneously coexisting but distinct levels of strength . . . positive strength is lowest, negative strength is highest, and static strength is midway between the levels of positive and negative strength.

In general, when positive strength is 100, then negative strength will be 140 (40 percent higher), and static strength will be 120, midway between positive and negative levels. Assuming only that you are testing fresh, rested muscles, at any level of strength, and that the dynamic tests are conducted at a relatively slow speed of movement. Fatigued muscles show a far different ratio, and tests conducted at faster speeds during the dynamic portions show a different ratio. But regardless of the level of fatigue, and regardless of the speed during the dynamic testing procedures, static strength will be midway between the positive and negative strength levels. Assuming that the same speed is used during both dynamic tests.

Static procedures provide the only meaningful test of strength ... dynamic tests, regardless of how they are conducted, produce only artifacts; tell nothing about the true level of strength.

Tests of positive strength are always an understatement of true strength, reduced by friction in the muscles, while negative tests produce an overstatement of true strength, increased by muscular friction. If the level of friction was known, then perhaps meaningful results could be produced by adding to a test of positive strength, or by subtracting from a negative test . . . but the level of friction, as a percentage of muscular force, changes as a result of two factors, speed of muscular contraction and momentary level of fatigue.

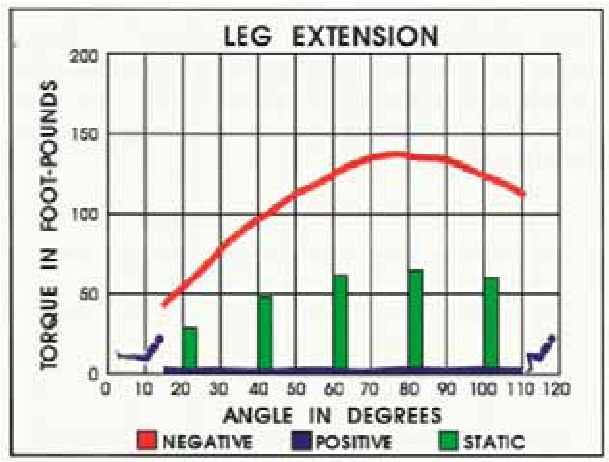


FIGURE 3-9 Compare these test results to those shown by Figure 3-8; this chart shows the three levels of tested strength, positive, static and negative, after a subject was exercised to the point that his positive strength was totally lost, while only 14 percent of his negative strength was gone, and while his true loss of strength was shown by his remaining level of static strength, reduced by 50 percent from its fresh level.

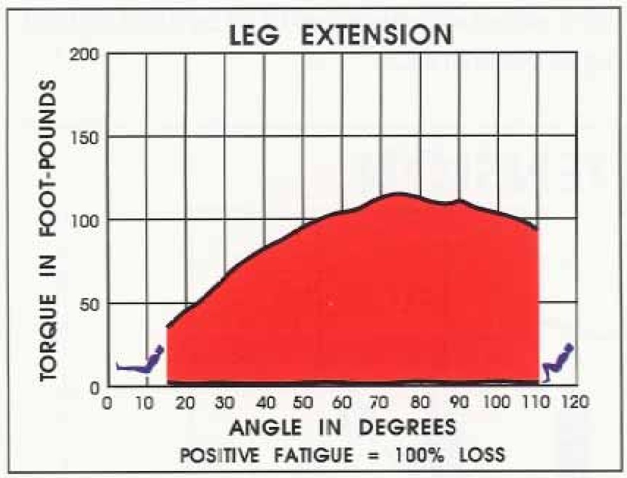


FIGURE 3-10 The level of fresh strength measured during a test of dynamic positive strength, compared to the level of remaining strength following a very hard exercise, an exercise continued to a point where the subject could no longer produce movement even with no resistance against such movement. His loss of fresh positive strength was 100 percent. The red area between the fresh and exhausted curves shows positive fatigue from the exercise. Compare these results to the two following examples.

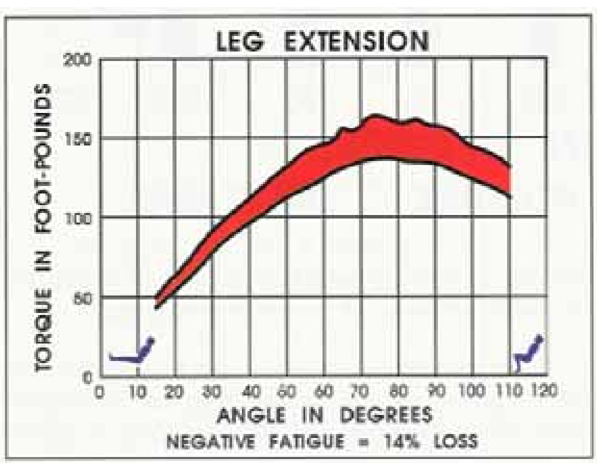


FIGURE 3-11 Tested for fresh negative strength prior to the exercise, the subject produced the highest curve of torque; when retested immediately after the exercise, produced the lower curve. The red area between the two curves shows negative fatigue from the exercise.

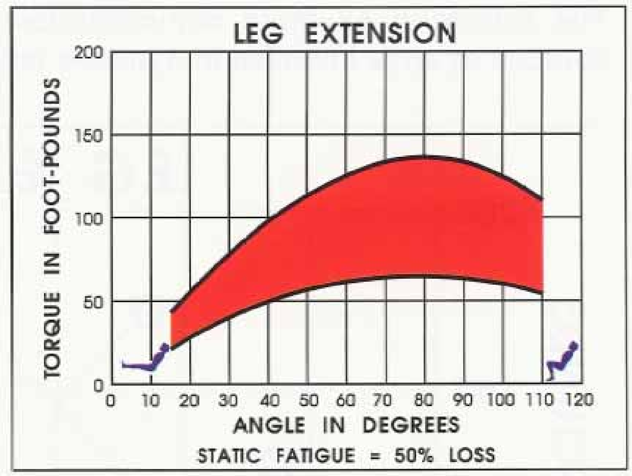


FIGURE 3-12 The actual losses of fresh strength were clearly indicated by the tests of static strength shown here. Positive tests grossly overstate the loss of fresh strength from exercise, while negative tests understate the true level of fatigue from exercise. But

static tests will show what actually occurred. The red area between the two curves shows static fatigue.

In 1985 and 1986, we conducted more than 200 medical seminars, with total attendance of several thousand people from every branch of medicine, and this provided the opportunity to test the levels of coexisting positive, negative and static strength with more than 2,000 subjects.

Most of these people were not exercised to the point involved in the above example; instead were tested for fresh levels of positive, negative and static strength, were then exercised only to a point where fatigue became obvious, and were then immediately retested for their remaining levels of strength. But at any remaining level of strength, fatigue was always overstated by the positive tests, understated by the negative tests, and accurately measured only by the static tests.

Even fresh levels of dynamic strength are biased by muscular friction, but the initial level of friction found in fresh muscles changes as fatigue is produced. When worked to a point where all of the fresh level of positive strength has been lost, the friction has then reached such a high level that it is equal to the force of maximal muscular contraction. Continued positive movement then becomes momentarily impossible; even though the actual level of fresh strength (force of muscular contraction) has been reduced by only fifty percent.

The following example demonstrates both physiological and psychological sources of error involved in dynamic testing procedures.

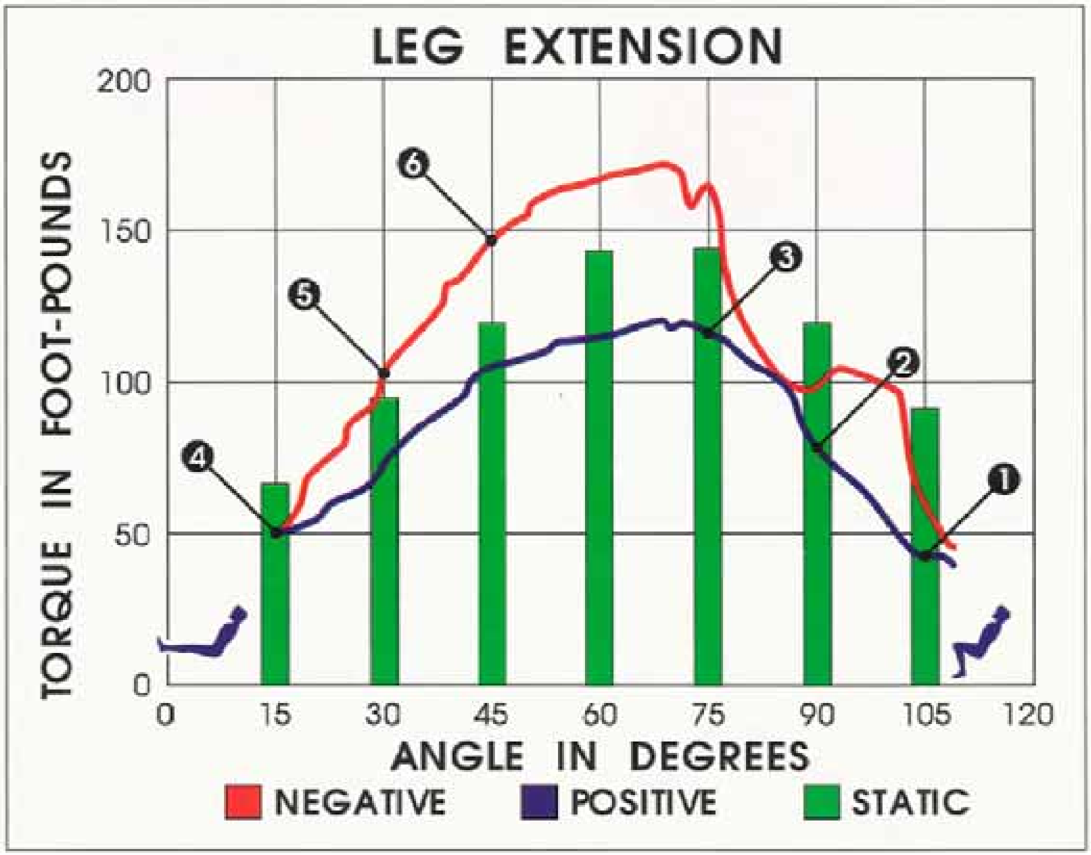


FIGURE 3-13 Look first at the right side of the chart, notice that the blue line which represents the positive strength curve indicates a positive strength of less than half of the static strength in that position. There is a dot in the static-strength bar-graph which represents positive strength in that position, a dot with an arrow pointing towards it, an arrow numbered 1 inside a circle. In that position, the positive strength should be about 83 percent of the static strength, but in fact was less than 50 percent.

This low level of positive strength in that position was produced by a factor which introduces error into all dynamic test results, the inability of the subject to recruit all of the available muscle fibers instantly. In a dynamic test, the movement starts instantly, but you cannot recruit all of your available muscular fibers instantly; will move well away from the starting position before the muscle is capable of producing its maximal level of torque in that position.

Now look at the dot in the next bar-graph to the left. Having moved that far from the starting position, the subject was still not producing an appropriate level of positive torque, was producing only about 70 percent of his static level of strength in that position, when he should have been producing above 83 percent.

By the time he reached the position represented by the third bar-graph, he was finally producing an appropriate level of positive torque; but during the first 35 degrees of movement his measured level of positive strength was too low. He could not recruit all of his muscular fibers quickly enough to produce a true test of positive strength in those positions.

Throughout the remainder of the positive test, his measured levels of strength stayed fairly close to what they should be as a percent of his static strength in those positions. But at the end of the tested range of movement he was starting to show an effect from another factor, he was losing strength as a result of fatigue. The positive repetition required about four seconds to perform, moving at a speed of 25 degrees per second throughout a range of approximately 100 degrees; and because of the continuous nature of the test procedure he was starting to lose strength from the onset of fatigue.

In general, subjects with a high percentage of fast-twitch fibers will recruit rapidly but will also fatigue quickly; whereas subjects with slow-twitch fibers will recruit more slowly but will not fatigue as quickly. Most subjects will suffer primarily from one factor or the other, but generally not from both; will produce strength curves that are too low on one end of the movement or the other, but not to a marked degree on both ends. This subject recruited slowly but did not fatigue very rapidly; indicating a high percentage of slow-twitch fibers in these muscles.

Having moved across the chart from right to left, following the progress of the positive strength test, look now at the point where we ended the positive test, the dot numbered 4 being both the ending point for the positive test and the starting point for the negative test. Moving now left to right, follow the red line that represents the strength curve during the negative dynamic test; notice first that the level of negative strength indicated in the starting position was far too low. Again the recruitment factor was responsible for a low test result; movement started and proceeded long before the subject could recruit all of the available fibers.

Follow the red line up to the position marked as number 5; having moved 15 degrees from the starting position, he was still producing far too little torque. This subject did not start to produce an appropriate level of negative torque until he reached a position about a third of the way through the entire range of tested movement, marked as number 6. His tested results were too low during the first third of the movement. Again a meaningless result ... or worse, a misleading result.

Then, during a large part of the rest of the tested range of movement, his results were compromised by another factor; but not a physiological factor in this case. Seeing the high levels of torque that he was producing, the subject backed off in his efforts . . . stopped trying to produce as much torque as possible. His tested levels of negative strength throughout the remainder of the procedure were far too low.

Until the additional errors produced by impact forces, body-mass torque and stored-energy torque are factored into the test results, any meaningful relationship between tested torque and true muscular strength is impossible. But it is also impossible to measure these factors during any form of dynamic test.

Twenty years ago, then providing no negative work with their machines, the promoters of isokinetic exercise went to great lengths in their attempts to label negative work as both worthless and dangerous. As a result of this campaign against negative work, some people still avoid it during rehabilitation. Avoid it to their great loss, because negative work is certainly one of the most important parts of exercise.

During the period of sixteen years that Nautilus Sports/Medical Industries, Inc., was owned and directed by me, several teams of highly-qualified people worked for ten years in continuous efforts to produce safe, meaningful, isokinetic testing machines based upon servo-power; and one team, headed by Lester Organ, M.D., produced the first servo-powered machine ever built for this purpose; but this machine was never offered for sale, although we used it for research purposes for several years, with thousands of subjects.

Was not offered for sale because it proved to be unavoidably dangerous; the longer we worked with it the better we understood the problems with such technology. Several of the previously-used illustrations were produced by this servo-powered, isokinetic machine, and we learned a number of things from its use; but primarily learned that the related problems would not permit us to place it on the market.

We settled upon static testing for the good and simple reason that no other method works; static testing is far more than the best method of testing strength, it is quite literally the only meaningful method of testing strength.

CHAPTER 4

ABNORMAL STRENGTH CURVES

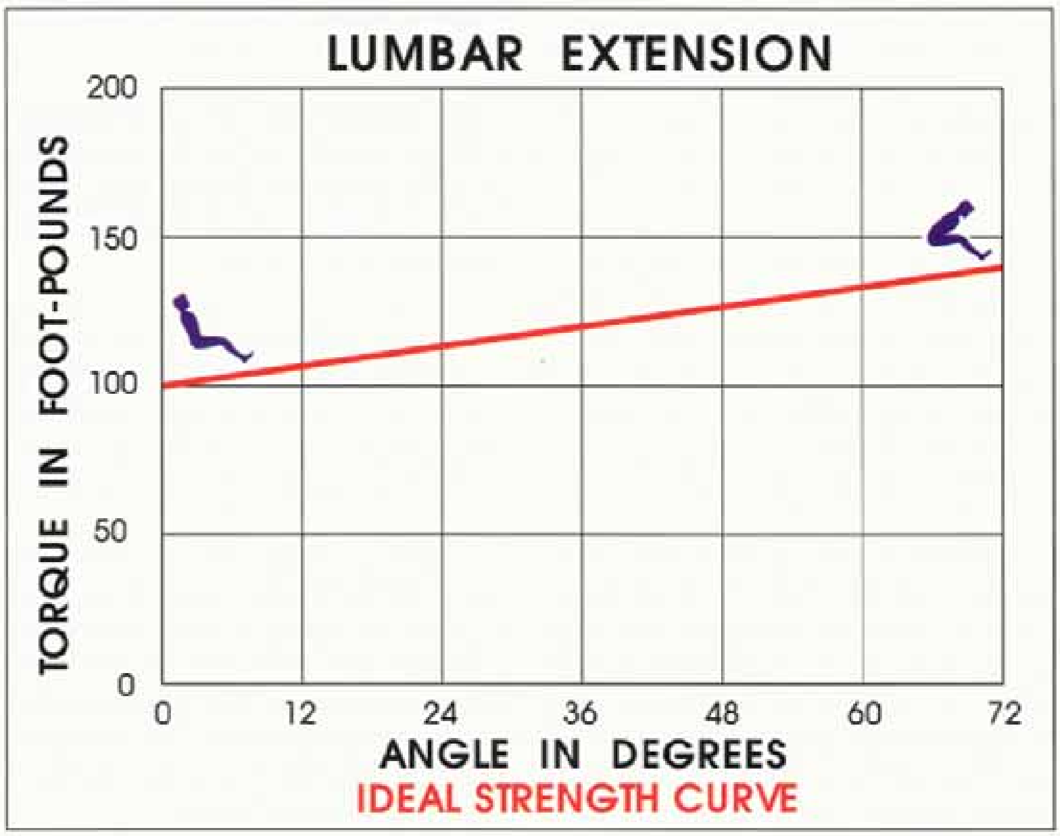


FIGURE 4-1 This chart represents a hypothetical, ideal curve of the functional strength of the muscles that extend the lumbar spine. If strength in the flexed position is 140 foot-pounds of torque, then fully-extended strength should be 100; with proportionate levels of strength throughout a full range of movement, and the strength curve should be a straight line. In this example, the indicated level of strength is far below an average level.

RESEARCH: A large group of normal subjects, male and female, exercised once each week for 20 weeks; were tested at the start, after 12 weeks, and after 20 weeks. At the start, the average ratio of strength was 2.3 to one . . . strength in the flexed position was 130 percent higher than It was in the extended position.

But after 12 weeks, the ratio had changed to 1.6 to one.

And after 20 weeks, the ratio was 1.4 to one; strength in the flexed position then being only 40 percent higher than in full extension. Gains near the extended position were far greater; indicating that the initial state of atrophied weakness was worse in the extended position.

When to perform a first test of spinal strength with a patient is a decision that must be based upon clinical judgment; some clinicians perform tests during the patient's first visit, and some perform no testing during the first several weeks of rehabilitation. Dr. Brian Nelson, of Minneapolis, has rehabilitated more than 4,000 chronic spinal patients with MedX equipment, with outstanding results, and he normally performs strength tests during the patient's first visit. Some other clinicians who are experienced with MedX equipment perform the first strength test after four weeks of specific exercise.

Research performed at the University of Florida College of Medicine, and elsewhere, has already established normal strength curves of spinal function, and any meaningful deviation from a normal curve is an indication of spinal pathology; but it must be clearly understood that such test results are not diagnostic, do not tell us the nature of pathology.

When the same abnormal curve of spinal strength has been produced by repeated testing procedures, we can be sure that a problem exists; but the nature of the problem cannot be determined by the tests.

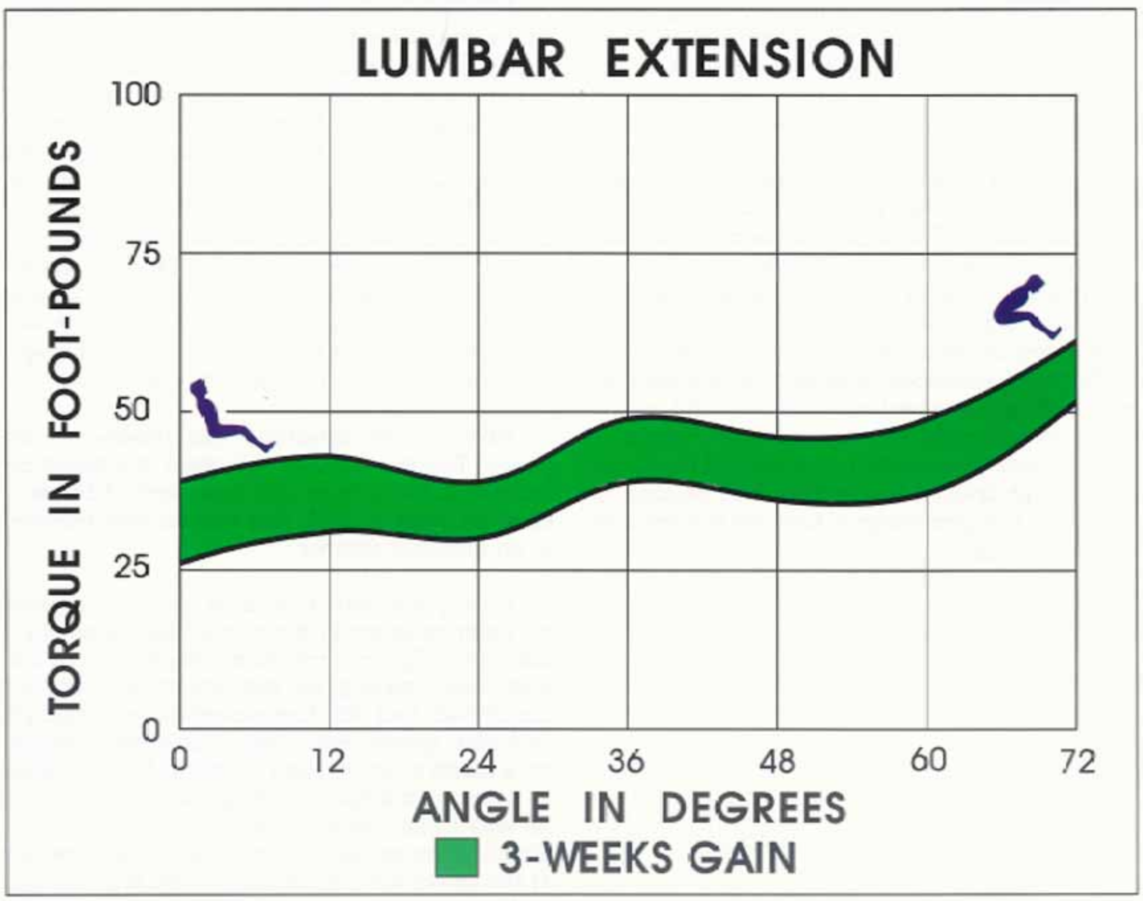
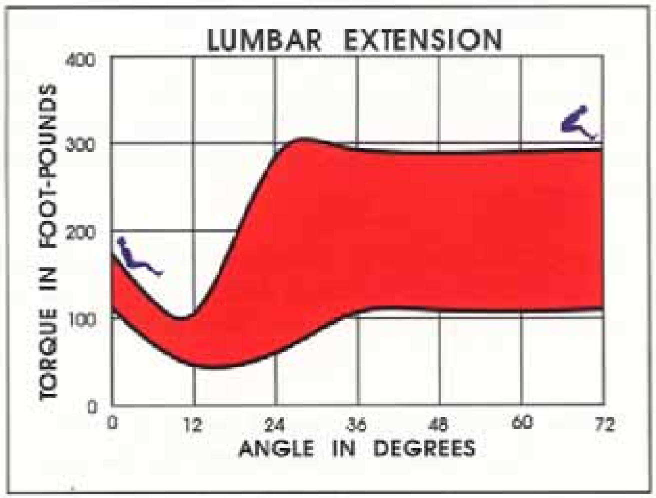


FIGURE 4-2 This chart shows the results of two tests of the full-range strength of the isolated muscles that extend the lumbar spine; the lowest curve shows the results of this patient's initial test, while the highest curve shows test results that were measured three weeks later. Both of these curves should have been a straight line, but instead both curves showed dips in strength in two positions; dips in strength that were repeated in the same positions in both tests. Such repeatability removes any doubts about malingering. In response to specific exercise, during this three-week period, this patient's strength in the fully-extended position increased by 50 percent, from an initial level of 26 foot-pounds of torque to a later level of 39 foot-pounds.



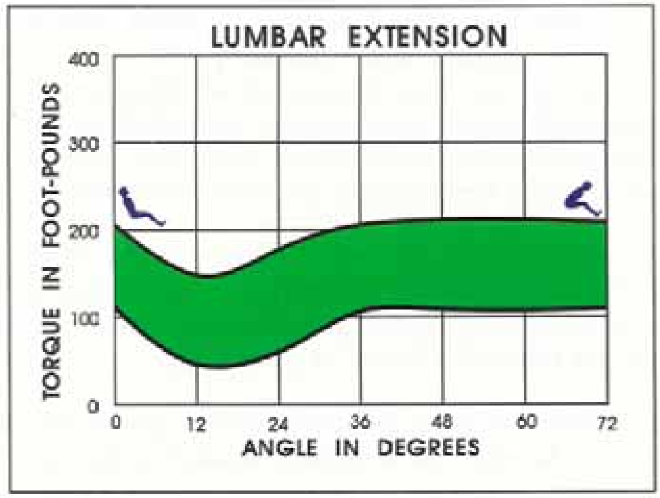


FIGURE 4-3 A meaningful test presupposes a cooperative subject, but some subjects do not cooperate for a wide variety of reasons apart from malingering; they may not understand the instructions, or they may be afraid to produce a maximal effort.

The top of the red area shows the curve produced during a test of fresh strength; with an obviously abnormal shape. The bottom of the red area shows the curve of remaining strength following an exercise continued to a point of failure; again showing an abnormal shape, but a different abnormal shape. So neither test can be considered valid; the only meaningful result produced by these tests was the magnitude of fatigue caused by a relatively light exercise that was performed between the tests. Fatigue resulting from the exercise is represented by the red area; a high level of fatigue from brief exercise, indicating a high percentage of fast-twitch fibers in the lumbar muscles.

FIGURE 4-4 Tested for a third time several hours later, a procedure intended to determine his recovery ability (some subjects fully recover from fatigue within a matter of minutes, while some do not recover for as long as several days), the subject shown by Figure 4-3 replicated the abnormal shape of the strength curve produced during his second test. The green area between the two curves shows recovery that occurred during the period of rest. A relatively slow rate of recovery; indicating that this subject should not be exercised frequently. But the most important result was the fact that the second and third tests both showed the same abnormal shape; indicating that both of these tests were valid.

NOTE: The abnormal test results shown above, Figures 4-3 and 4-4, were produced on October 8, 1987; more than three and a half years later, on June 1, 1991, this subject was retested in an identical manner.

During the period of more than three years between these tests, this subject exercised regularly on a Cybex lower-back machine; had become very strong on that machine, and was convinced that his lumbar-extension strength was also greatly improved. But when retested on a MedX machine, he proved to be more than 22 percent weaker in the spinal muscles than he was three years earlier. And the abnormal shape of the earlier strength curve was repeated at the lower level of strength. Most of the exercises now being used for the lower back have no effect on the spinal muscles; will increase the strength of hip and thigh muscles, but will not help the spinal muscles.

Nearly a year later, on May 18,1992, this subject was tested again on a MedX Lumbar-extension machine, and the strength of his isolated lumbar-extension muscles was identical to the level measured about a year earlier. No change In lower-back strength, even though he had continued to exercise on the Cybex lower-back machine and had continued to increase his strength on that machine.

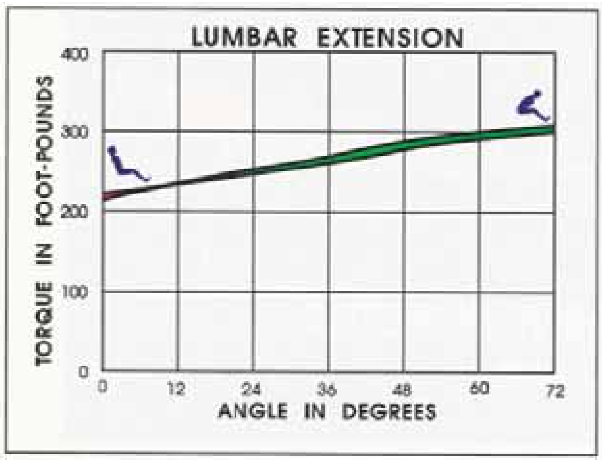


FIGURE 4-5 Testing performed immediately before and after a hard exercise on a Nautilus lower-back machine produced the two strength curves shown above. The exercise had no effect on the muscles that extend the lumbar spine. In six of the seven positions tested, strength was slightly higher following the exercise on the Nautilus machine, and in one position was slightly lower. Overall strength (area under the curve) was 2.5 percent higher following the Nautilus exercise than it was before the exercise. Compare these results to the following example; produced when the same subject was exercised on a MedX machine.

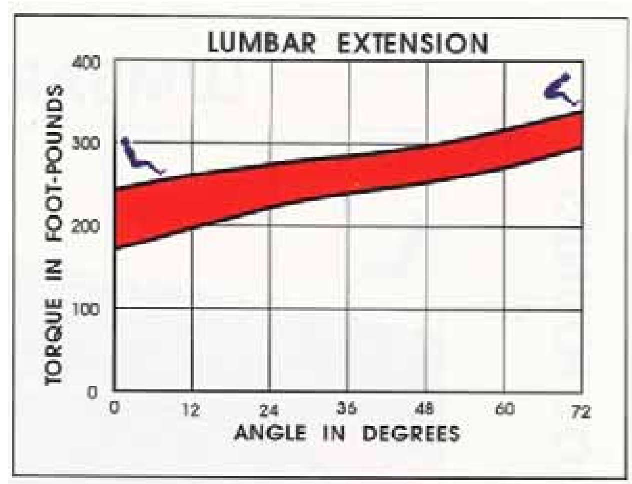


FIGURE 4-6 Testing conducted immediately be fore and after exercise on a MedX Lumbar-extension machine produced these results; the fresh level of strength was reduced by an average of 18.4 percent throughout a full range of movement, as an effect from only six repetitions of the exercise. The red area shows fatigue from the MedX exercise. In contrast, eleven repetitions on the Nautilus machine had no effect on the spinal muscles. The total isolation of the lumbar-extension muscles provided by the MedX machine produces specific exercise; the only source of productive exercise for spinal muscles. When the muscles of the hips and thighs are involved in the exercise, as they are in all other exercises, gains in strength that are produced will be limited to the muscles of the hips and thighs; with little or no resulting benefit for the muscles of the lower back.

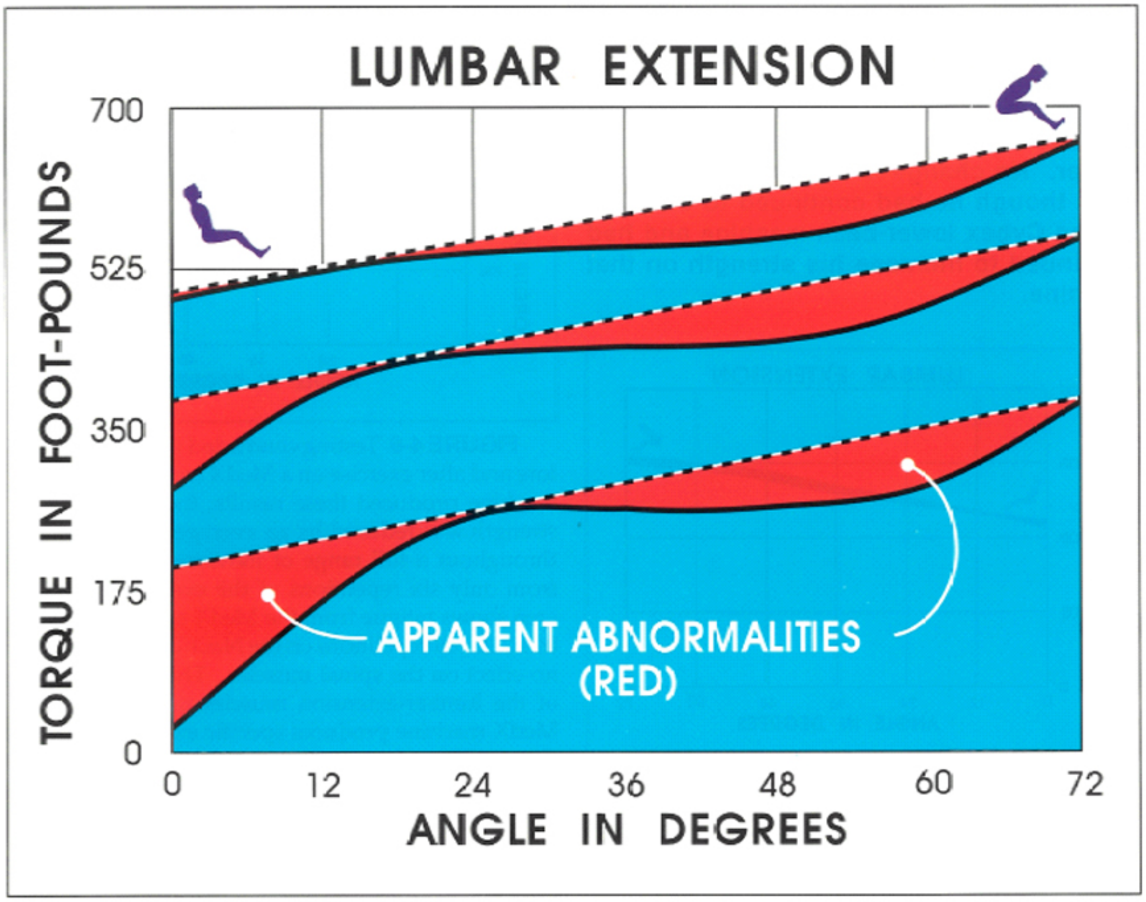


FIGURE 4-7 Three tests of fresh strength conducted over a period of 76 days. The curve above the lowest blue area shows the initial level of strength. The two red areas immediately above this lowest curve represent apparent abnormalities; the computer added a normalizing curve, and then filled in the areas between the actual curve and the ideal curve with red to call attention to the large, red triangle on the lower left, and the red, boat-shaped area on the lower right.

During a second test, following six weeks of specific exercise, the middle curve was produced; in the meantime, the level of fresh strength had been markedly increased, and the size of the red triangle on the left had been reduced, while the red, boat-shaped area remained unchanged.

The highest of the three curves shows fresh strength after 76 days of specific exercise; by which point the red triangle on the left was gone. The initial red triangle did not represent an actual abnormality; instead, indicated an advanced state of atrophy in that position; atrophy that was quickly corrected by specific exercise. But the red, boat-shaped area was still unchanged even at a much higher level of strength; this was an actual abnormality that was not corrected by exercise during that period. But a year later, this abnormal shape in the strength curve was gone; and he then produced a normal shape during his tests.

This patient suffered chronic lower-back pain for twelve years prior to the date of his first test; pain that was removed by the time the second test was conducted, pain that has not returned for a period of more than six years following the second test.

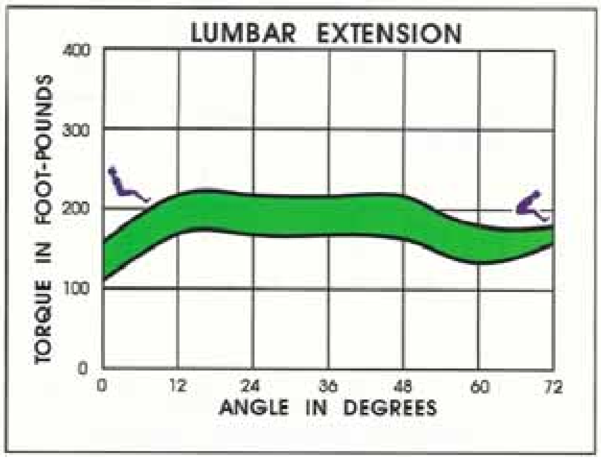


FIGURE 4-8 Tested before and immediately after an exercise that was continued to a point of failure, this subject showed a gain in strength following the exercise; and he produced fresh and exhausted strength curves with the same abnormal shape, clear proof of valid test results.

For a period of several years, this was the most extreme example of a slow-twitch response that we saw among many thousands of tests; slow-twitch muscle fibers causing such subjects to show the same level of strength before and after exercise, and, in some cases, causing a gain in strength following the exercise. This subject was 23 percent stronger after the exercise than he was before the exercise.

But since then we encountered an even more extreme example of a slow-twitch response; during his initial three-part testing and exercise procedure, this subject was 25 percent stronger following the exercise than he was before the exercise. His first four test/exercise procedures, performed at intervals of approximately one week, increased his overall fresh strength in excess of forty percent; with gains of more than fifty percent in some positions. Gains that were produced during a period when he was exercising in no other way.

During the exercise performed as part of his first test/exercise procedure, he failed after ten repetitions with resistance of 150 foot-pounds. Then, during his third procedure, about two weeks later, he performed eleven repetitions with 180 foot pounds of resistance; an increase of more than 20 percent in dynamic, full-range strength produced by only two previous exercises.

MALINGERING

Experienced individuals have been unable to duplicate a faked abnormal strength test using MedX equipment; doing so would require producing the same submaximal levels of torque in the same positions throughout a full range of movement, which is probably impossible. It is easily possible to produce a zero level of muscular torque, and easy to produce a maximum level of torque; but repeating an exact level of submaximal effort is very difficult if not impossible.

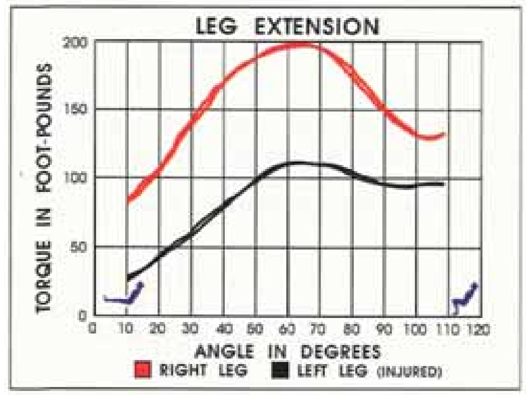


FIGURE 4-9 The higher, red curves on this chart represent two tests of the fresh strength of a normal leg; tests conducted two days apart. The lower, black curves show the results of two tests with an injured leg; tests also conducted two days apart.

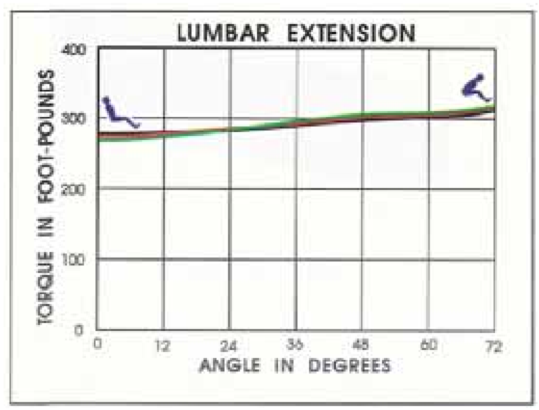


FIGURE 4-10 Three tests of lumbar-extension strength performed at intervals of 24 hours; showing a difference of less than one percent. Cooperative subjects will produce repeated test results that are so close to being identical that any difference is insignificant; a lack of such consistent results is an indication of a noncooperative subject.

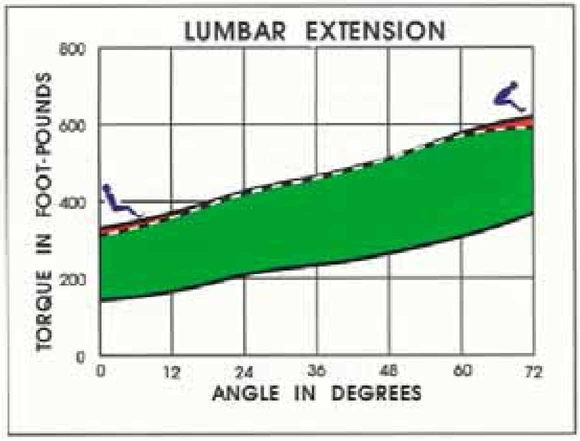


FIGURE 4-11 Three tests of full-range, lumbar-extension strength produced by a fast-twitch subject. One of the two highest curves on this chart represents fresh strength; while the lowest curve shows strength following brief exercise.

The second of the two highest curves shows a test of recovered strength conducted about four hours after the initial three-part procedure. Within that rest period, fresh strength had been largely recovered; but near both ends of the movement range, the recovered level of strength was still slightly below the fresh level. Recovery from fatigue is selective in regard to position.

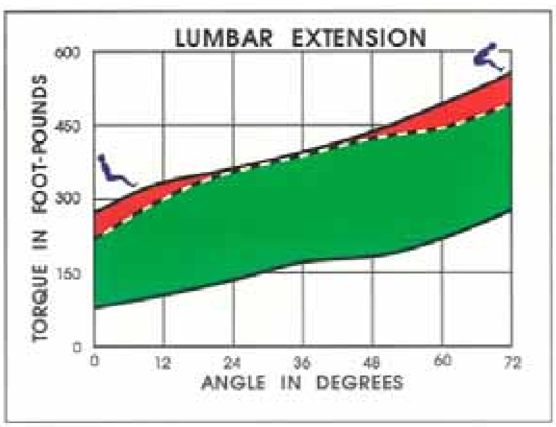


FIGURE 4-12 The same subject shown in Figure 4-11; tested in the same way at a lower level of strength; and then not permitted enough time for rest between the post-exercise test and the recovery test. Fresh strength was totally restored in the midrange of movement, while remaining fatigue was still evident near both ends of the movement range. The green area shows recovered strength, while the red areas show remaining fatigue.

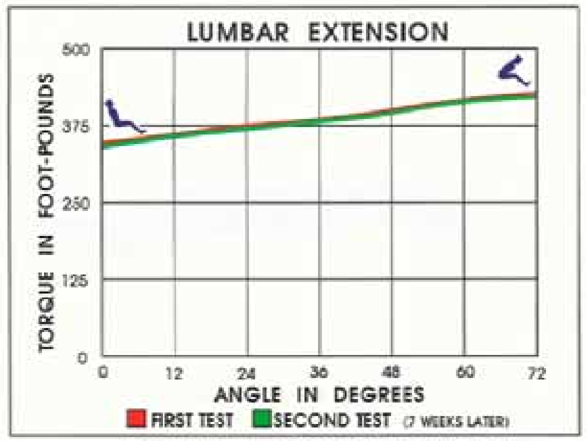
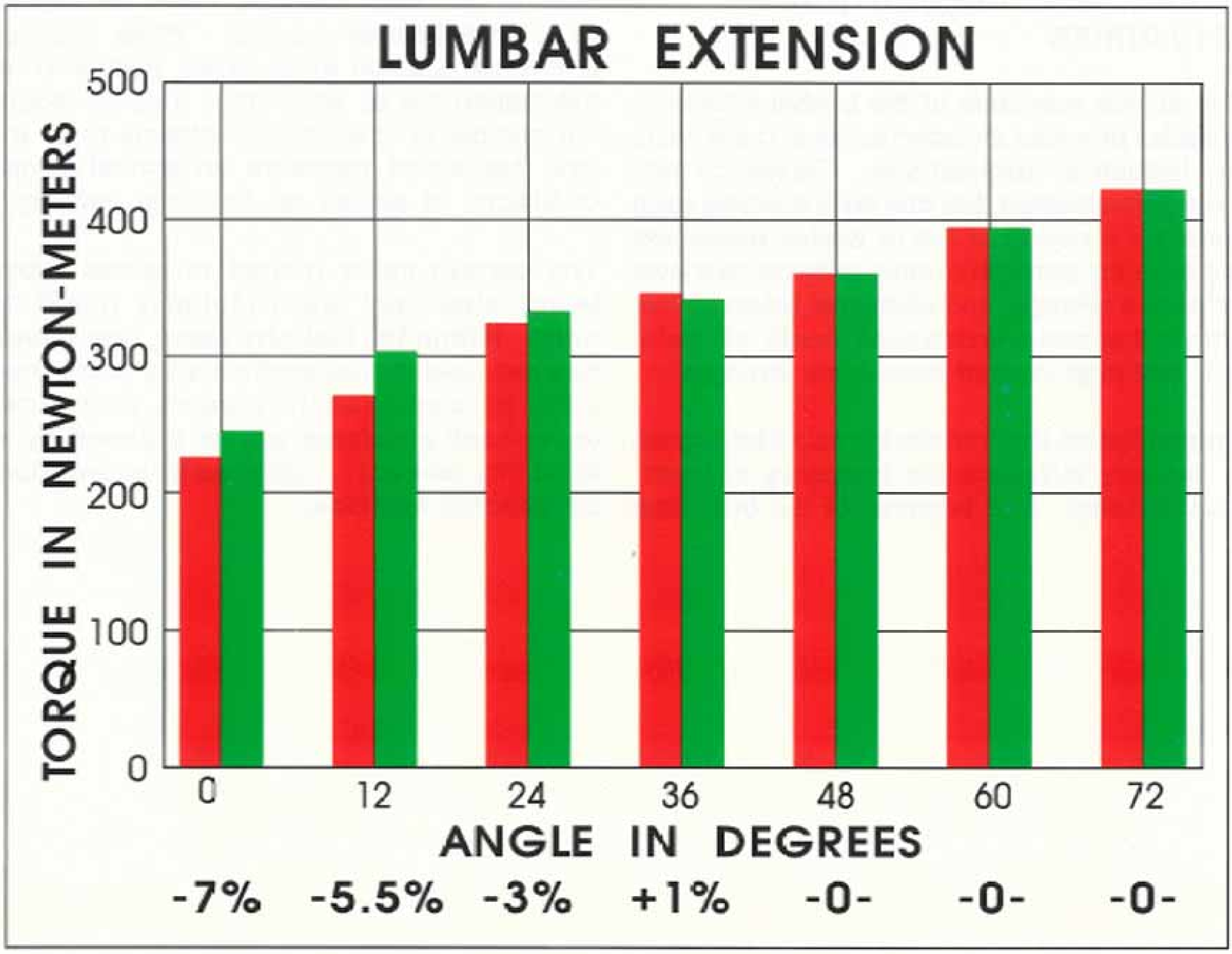


FIGURE 4-13 Having previously increased the functional strength of his lumbar muscles by more than 117 percent in the flexed position and by 300 percent in full extension, as a result of a relatively brief period of specific exercise, this subject then performed no exercise or testing for a period of seven weeks; this chart compares his strength after the exercise program to his still remaining strength following seven weeks without exercise. There are two strength curves shown on this chart, but they are so close to being identical that they appear to be only one curve; his loss of strength was effectively zero even after seven weeks of inactivity.

Subsequent research with large numbers of subjects has established that one specific exercise performed for the lumbar-extension muscles every four weeks will maintain all or most of a previously-produced level of peak strength.



RESEARCH: Following a twelve-week program of specific exercise for the muscles that extend the lumbar spine, during which period large increases In strength were produced throughout a full range of movement, a group of normal subjects changed to a schedule of only one exercise every four weeks. After twelve weeks on this reduced schedule, during which period they performed only three exercises for the spinal muscles, they were retested for remaining strength.

In the fully-extended position, their previous level of peak strength had been reduced by only 7 percent; with a one percent increase In strength In the midrange of movement, and with no change In strength in the first half of a full range of possible movement.

The paired bar-graphs show peak strength compared to remaining strength after twelve weeks of reduced training; the graph on the right in each pair shows peak strength, while the graph on the left shows remaining strength. Having increased the strength of the spinal muscles with specific exercise, very little In the way of additional exercise is required to maintain the peak level of strength.

EXERCISE for PREVENTION of INJURIES

The unique response of the lumbar-extension muscles provides an opportunity of great value for industrial applications. Research has clearly established that one brief exercise each week for a period of ten or twelve weeks will increase the strength of most subjects to a level far above average; and additional research has shown that one exercise each month will maintain that high level of lower-back strength.

Properly used, this knowledge could be applied in industry to reduce the frequency of lowerback injuries. And because of the brief time required for such exercise, could be applied In a cost-effective manner. While exercise is not the solution in all cases, neither in rehabilitation nor as prevention, it could reduce the number of lower-back problems to an extent that would represent an annual saving of billions of dollars to American industry.

The current costs related to spinal injury being what they are, eventually it will be done. Within the last fifty years, prevention has reduced dental problems by more than sixty percent; and fifty years from now, lower-back problems will be reduced by at least fifty percent… reduced by prevention, by specific exercise.

CHAPTER 5

REHABILITATION

All *parts of the body* which *have a function,* if used in *moderation and exercised, become* thereby *healthy and well-developed and age* slowly, but if unused and *left idle* they *become* liable *to disease, defective and age* quickly. *Hippocrates*

The value of exercise for rehabilitation has been recognized in Europe for more than two-thousand years, but was generally overlooked in this country until about fifty years ago. During the last few years, a wide variety of treatment modalities have been introduced, all intended to reduce pain; but proper exercise still remains the best, and probably the only truly productive, protocol for rehabilitation. With musculoskeletal injuries, there are only two choices: surgery or exercise, or a combination of the two. Other treatment may reduce or temporarily remove pain; but nothing else seems to enhance, repair and improve function, which is the goal.

While sometimes required, immobilization should usually be avoided, and reduced to the shortest period possible in all cases; tissue changes from immobilization occur very rapidly, and long immobilization may produce changes that can never be corrected.

Current imaging technologies, X-rays, CT scans and MRI scans, provide a clear diagnosis in only a small percentage of spinal pathologies; in most cases idiopathic situations are involved, some of which will improve almost regardless of the treatment applied. Spontaneous improvement that has been largely responsible for a wide variety of current treatment protocols of no proven value; whatever was tried most recently usually gets the credit in such cases.

Exercise for rehabilitation involves only a few simple points: one, kind of exercise ... two, frequency of exercise ... three, level of resistance . . . four, number of repetitions ... five, style of performance. Apart from things to avoid, those five points are all that need to be considered.

KIND OF EXERCISE

Dynamic exercise with variable resistance; variable resistance because strength varies throughout any full-range movement, sometimes varies by several hundred percent from one position to another within the same range of movement. If the level of resistance remained constant throughout the movement, you would be limited by strength in the weakest position, and the resistance would be too low in stronger positions.

The exercise should also provide both positive and negative resistance; without negative resistance, full-range exercise is impossible; without negative resistance, there can be no resistance on either end of a full-range movement, and benefit from the exercise will be produced primarily in the midrange of movement.

Range of movement should be capable of providing full-range exercise, or any desired part of a limited range of movement.

While resistance can be provided by weights, springs, hydraulic cylinders, a servo motor, or by a number of other possible sources, the best choice still requires the use of weights. All other resistance sources have unavoidable limitations, and in some cases produce dangerous levels of impact forces.

FREQUENCY OF EXERCISE

Exercise for the purpose of increasing function, strength and muscular endurance, should never be performed more than three times weekly, and better results will sometimes be produced by only two weekly exercises, or even one.

NOTE: The opinions expressed in this chapter (and elsewhere in this book) on the subject of rehabilitative exercise are based upon personal experience in the field of exercise for a period of more than fifty years, and upon personal research in this field that has now been ongoing for more than twenty years. Like any other treatment in the field of medicine, the application of rehabilitative exercise must be guided by clinical judgment; which means that it is impossible to recommend a treatment protocol that will be suitable for all patients.

LEVEL OF RESISTANCE

Resistance should be low enough to permit at least eight full-range movements, but high enough to prevent more than twelve. When twelve repetitions can be performed, the resistance should be increased by five percent.

NUMBER OF REPETITIONS

Fast-twitch subjects should use a lower range of repetitions than indicated above, from six to nine repetitions. Some slow-twitch subjects will produce greater gains in strength with a range of fifteen to twenty repetitions.

STYLE OF PERFORMANCE

Perhaps the most important consideration: a proper style of performance requires a relatively slow speed of movement. Too slow provides all of the benefits and produces none of the potential problems, while too fast avoids some benefits and does produce problems, generally problems resulting from high levels of impact force.

At the start of the first repetition, muscular contraction should be produced gradually, and should be slowly increased until the start of movement is produced. Once movement at a slow speed has started, the level of effort should remain just high enough to continue slow movement. Do not increase the speed as movement continues. When approaching the end of the possible range of movement, speed should be smoothly reduced to zero. Which does not mean that you should relax in that position; but you should pause briefly in that position. After a pause of one or two seconds in the fully-contracted position, movement should be started in the opposite direction; gradually and smoothly, and continued at a slow speed.

But you should not pause, nor relax, upon returning to the starting position; instead, a smooth change of direction should be produced without pause, and with no sudden or jerky movement. The exercise should be continued in that fashion until it becomes momentarily impossible to perform another full-range movement against the resistance.

How many sets of the exercise? One. Additional sets usually serve no purpose and may produce a state of overtraining with some subjects.

Contrary to a somewhat common misconception, the force involved in the negative part of the exercise is actually lower than the force during the positive part. During the positive work you must produce force equal to the resistance, plus additional force equal to the friction in the machine; but during negative work the machine friction reduces the force slightly below the selected level of resistance. If machine friction was one percent of the level of resistance, the force would be 101 during the positive work, with resistance of 100, but negative force would be only 99 with the same level of resistance.

As fatigue from the exercise makes it more difficult to continue, some subjects may start jerking instead of continuing with smooth movement; by jerking they are trying to invoke the stretch reflex in order to continue; but this is not required and may produce high levels of impact force, so should not be permitted. The exercise should be stopped when the subject is no longer capable of completing a full-range movement without jerking; at that point you have done everything necessary, and have avoided any potential problems.

Working to failure does not mean exercise continued to a point where all of the fresh strength is lost, and does not mean working until any movement is momentarily impossible; but does mean that the exercise should be continued until a full-range movement is momentarily impossible without jerking. At that point your strength is not zero, instead has been momentarily reduced by fatigue to a point where your remaining strength is slightly below the level of resistance; if the resistance is 100 pounds, you will be forced to stop when your remaining strength drops to a level of only 99 pounds. With most subjects, when they fail, the fresh level of strength has been momentarily reduced by only about 20 percent; but that level of fatigue is all that is required to stimulate following strength increases.

Properly performed exercise is both safe and productive; most subjects will respond with relatively fast and steady increases in strength until reaching a level dictated by their individual potential makes additional gain impossible. When steady increases in strength are not being produced, the first thing to suspect is that you are performing too much exercise; try doing less before trying anything else.

HUD

Modern military airplanes use a flight-management system called HUD, heads-up display. All of the absolutely essential information, and nothing extra, is projected on the windshield so that the pilot can fly while looking outside the airplane. In exercises where the range of movement makes it possible for the subject to constantly watch the computer monitor, MedX machines provide a similar capability; the subject can clearly see his position within a range of movement, can see the exact level of the resistance force, and can tell if his speed of movement is proper; is constantly provided all of the information required for a proper style of performance of the exercise.

CAUSE or EFFECT?

As the level of fatigue increases, the coexisting level of friction in the muscles also increases; but it is impossible to tell which is cause and which is effect (does fatigue increase friction, or does friction increase fatigue?) since they go up and down together.

Friction is also increased by a faster speed of movement, and reduced by a slower speed, which is why you are forced to reduce speed of movement as you near the end of a hard exercise; when continued movement at the same speed becomes momentarily impossible, you can continue to move if you reduce the speed; slowing reduces the friction and may permit the performance of one or two additional repetitions after continued movement at the initial speed has become impossible. Which means that the initial speed should be slow .. . later speed should be slower ... and that the exercise is properly completed only when momentary speed becomes zero.

More than fifty years ago, attempts to test strength were performed using barbells or weight machines, by trying to determine just how much weight the subject could lift for only one repetition; later called 1 RM testing, one repetition maximum, this system has been used in a number of research programs.

Another system of testing involves the performance of ten repetitions with as much weight as possible; this being both a safer system of strength testing, because the weight must be lower, and a better system for several reasons. But both systems have Problems primarily resulting from the fact that you must guess right each time in order to produce meaningful results. If you test with too much weight, then you will fail to complete the lift; but if you guess too low, then you cannot tell just how much more weight you might have lifted.

But an awareness of this system does provide the ability to judge your progress from workout to workout without performing strength tests each time; if you fail after ten repetitions with 100 pounds, and then fail after eleven repetitions during the next workout, this does not mean that you are ten percent stronger, but it does mean that your strength has increased. A ten percent strength increase would be indicated only if *you* failed after the same number of repetitions, but with ten percent more weight.

The above being true only if both style of performance and speed of movement remain constant; if you move faster you will be able to perform more repetitions, while a slower speed will reduce the number of repetitions. Time under load being the important factor here, the higher the level of muscular force, the shorter the time it can be maintained, and vice versa; assuming that the level of resistance is high enough to prohibit aerobic work.

NO CONTRADICTION

The last paragraph above may appear to contradict a statement in an earlier paragraph; but no actual contradiction exists. Earlier, we mentioned that slowing the initial speed of movement may permit you to perform one or two more repetitions by reducing muscular friction ... later, we said that less repetitions are possible with a slow speed of movement; an apparent contradiction.

But in fact both statements are correct; current knowledge and technology do not permit meaningful measurement of metabolic work, and trying to do so with measurements of mechanical work is meaningless; a machine must produce movement to perform work, but a muscle can work without movement, static work, muscular force of contraction with no resulting movement. For more than fifteen years we tried, but failed, to measure metabolic work based upon force x time, the amount of force multiplied by the time the force was maintained; but we eventually realized that such measurements cannot be provided in a meaningful fashion.

But the higher the level of force, provided only that it is above the threshold of anaerobic work, the shorter the length of time that it can be maintained. If maximum-possible force was 100, you might maintain that level for only ten seconds; but if force was reduced to 90, then you might maintain the force for twenty seconds; eventually, having reduced the force to a very low level, you might maintain it for several hours.

During an exercise, a higher number of repetitions will be produced at a faster speed because each repetition requires less time, force x time (time under load) for each repetition is reduced. And a greater number of repetitions will be produced even though the faster speed increases the level of muscular friction. But in the later stages of fatigue, as you approach a point of failure, slowing the speed may permit one or two additional repetitions by reducing muscular friction.

MUSCULAR SORENESS

All we really know about muscular soreness is that it is misnamed; the contractile tissue in muscle does not have the type of nerves required to indicate pain, so it is not the actual working part of the muscle that feels pain. It may be connective tissue, but what ever it is can become painful as a result of exercise. But such pain is highly inconsistent; some hard exercises cause resulting pain, and some do not. A first hard exercise may cause pain that occurs a day or more later; but a second hard exercise then serves to reduce the pain, so it is obvious that exercise can both cause pain and reduce or remove pain.

But if exercise is performed on a regular basis then any initial pain will usually be gone within a few days at most, and will not return as long as regular exercise is continued. Even initial muscular soreness can be avoided by starting a program of exercise gradually; the first exercise session should not be continued to failure, stop while still capable of rather easy movement ... and then, workout by workout, gradually increase the level of effort until you are working to failure. When this is done properly there will be little or no resulting muscular soreness.

RATIO of STRENGTH to ENDURANCE

With a majority of a random group of subjects, strength and anaerobic endurance go up and down while maintaining the initial ratio. Most subjects, if they can perform ten repetitions with 100 pounds of resistance, can perform only one repetition with 120 pounds; and this ratio of strength to endurance will change very little as strength is increased by exercise.

But some subjects have far different ratios of strength to endurance, and some subjects do change their ratio as strength is increased. The following illustrations demonstrate different ratios of strength to endurance.

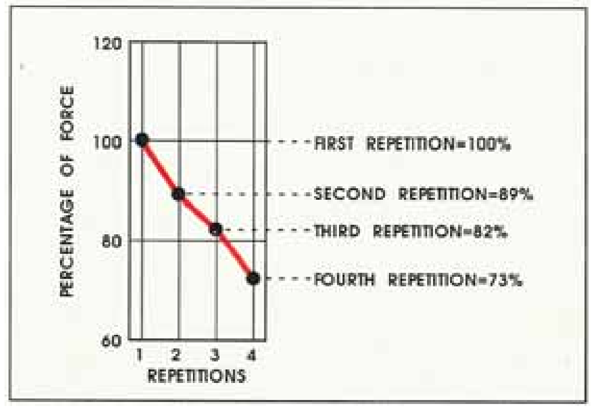


FIGURE 5-1 Maximum-possible levels of torque produced on a servo-powered, isokinetic, leg-extension machine during four consecutive repetitions. Having measured torque during the first repetition, the computer then compared the three following repetitions as a percentage of the first repetition; the purpose being to measure the loss of fresh strength produced by each maximum repetition.

This was a fast-twitch subject, and his fresh strength dropped rapidly from repetition to repetition; first repetition was 100... second was a bit above 89, showing a loss of more than ten percent of fresh strength as a result of the first repetition… third was between 82 and 83, a loss of about seven percent of fresh strength from the second repetition . . . fourth was 73, a loss of more than nine percent of fresh strength from the third repetition. A total loss of fresh strength of 27 percent from the first three maximum repetitions. A very high level of fatigue from brief exercise; a typical fast-twitch response.

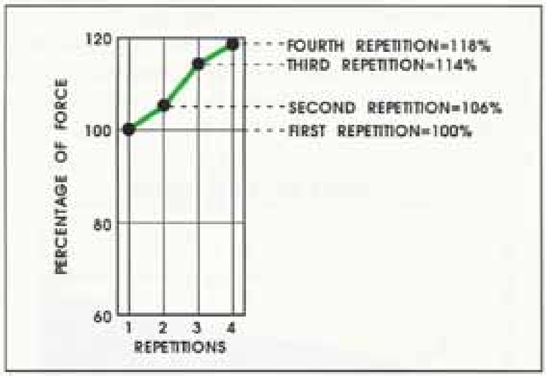


FIGURE 5-2 Conducted in the same manner, this test with a slow-twitch subject showed far different results; the level of torque increased during the first four repetitions, was 18 percent higher during the fourth repetition than it was during the first repetition.

Consider the implications of such individual differences for athletic competition; the normal warming-up procedures prior to competition would improve the following performance of the slow-twitch subject, but would greatly reduce strength of a fast-twitch subject for the following performance.

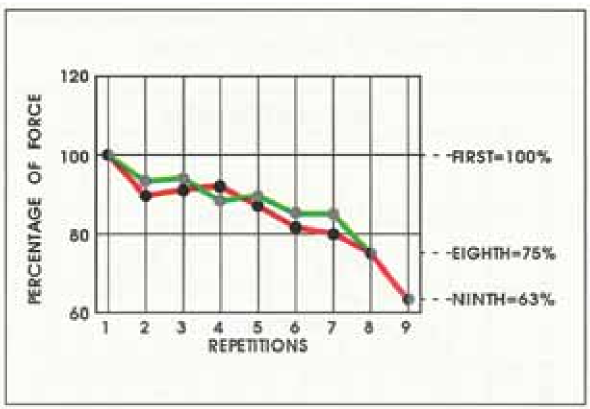


FIGURE 5-3 Tests with a subject having a usual mixture of fiber types in the quadriceps muscles; continued for nine maximum repetitions and comparing his right leg to his left leg. Fresh strength was reduced *by 37* percent during repetition number nine, indicating an average loss of four and one-half percent of fresh strength per repetition during the first eight repetitions.

But all of these were maximum-possible repetitions; during exercise, if failure occurs after ten repetitions, then the first nine repetitions were submaximal. With most subjects, exercised in the usual manner, fresh strength will be reduced by about 20 percent, an average loss of fresh strength of 2 percent per repetition.

Such individual differences are critical during rehabilitation; subjects must be exercised with careful consideration of both their fiber type and their recovery ability.

BLOOD PRESSURE

During exercise, most people seem to have an instinctive desire to grip with their hands; even in exercises where the hands and arms are not involved, and this is a practice that should be avoided. Muscular contraction increases blood pressure; but there is no relationship between the mass of muscle involved in the contraction and the resulting elevation in blood pressure.

Maximal contraction of one of the quadriceps muscles will usually raise the blood pressure about 50 points; but maximal contraction of both legs simultaneously will produce the same result, a 50 point elevation in blood pressure. So it is not the mass of involved muscle that matters.

Maximal contraction of the arm-flexor muscles of the upper arm will usually increase blood pressure by about 80 points; a far smaller muscle-mass but a greater elevation in blood pressure.

But the most dramatic effect on blood pressure is caused by maximal contraction of the muscles that produce gripping with the hands; blood pressure in this case is so high it is difficult to measure. For obvious safety reasons, such elevation of the blood pressure should be avoided, and can be avoided; do not grip during exercise; instead, maintain the hands in a loose, semi-relaxed position.

In the lumbar-extension machine, handles are provided; but should not be used for gripping; these handles are provided for another purpose, serve only as a known position for maintaining the hands during test and exercise procedures. Moving the hands during the procedures would change the body-part torque and introduce error into test results; so the position of the hands should not change.

CHANGING STRENGTH CURVES

An accurately measured strength curve provides a clear picture of strength throughout a full range of movement; but does not always tell you what it can be, or should be. Strength curves change; change in response to exercise or as a result of atrophy.

Once the shape of a normal strength curve is known, then a test that produces an abnormal shape can be easily recognized; if the same abnormal shape is produced during later tests, then you have clear proof of an actual problem, but the nature of the problem is not always established by the shape of the curve.

When an apparent abnormality is indicated by an initial test, and confirmed by the same shape being replicated during later tests, but then rapidly changes during rehabilitation, you are probably dealing with an initial state of atrophied weakness; atrophy that will usually be quickly corrected by regular exercise. But if, instead, the initial abnormal shape Is maintained as strength increases, then you are dealing with idiopathic factors; caution should be continued as long as an abnormal shape in the strength curve persists.

A limited range of movement is an abnormal shape; the strength curve should be longer on one end, or on both ends. Limited range of movement can be caused by either or both of two factors, muscular weakness or some form of mechanical limitation that prevents additional movement beyond a certain position

Movement of the body produces internal resistance against continued movement; when the existing level of muscular strength has produced movement to a point where the coexisting level of internal resistance, stored energy, has been increased to an equal level, then continued movement is impossible. At that point you have equal and opposite forces. But when an initial limited range of movement is produced only by muscular *weak*ness, the range of movement will be increased as strength is increased in response to exercise.

Limited range of movement produced only by muscular weakness can usually be identified; in such cases, the tested level of functional torque will always be zero at the end of the possible range of movement. Zero because the true muscular torque, NMT, is then being opposed by an equal level of nonmuscular torque coming from an opposite direction. But when the tested level of functional torque is anything in excess of zero, at the end of the possible range of movement, then a mechanical limitation of some sort is preventing additional movement. Such mechanical limitations can seldom be identified, and should always be treated cautiously; do not attempt to increase the range of movement by stretching.

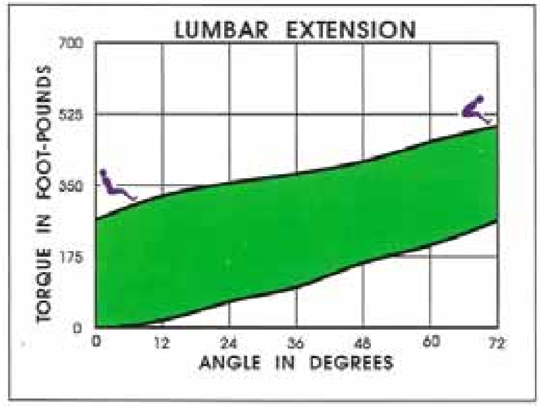


FIGURE 5-4 When first tested, this subject could not produce any measurable torque in a position of full extension. In that position, his existing level of muscular torque was equal to stored-energy torque acting in the opposite direction; so functional strength was zero. Six degrees forward from full extension, he could produce only 4 foot-pounds of functional torque. Five months later, his strength in that position had increased to 2% foot-pounds of functional torque.

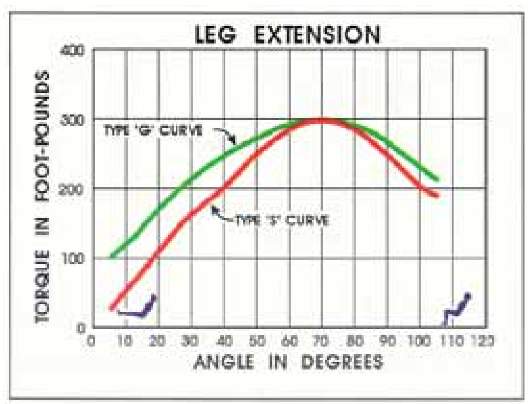


FIGURE 5-5 The strength curve produced by quadriceps testing is usually relatively low in the flexed position, highest as you near the midrange of movement, and lowest near full extension of the leg, a bell-shaped curve; but there is a wide range of

possible shapes even with normal subjects; differences in shape resulting primarily from previous exercise experience. Untrained, but normal, individuals usually have a very low level of strength near full extension of the leg, so they have the potential for large increases in strength in that position.

But some untrained subjects have a much flatter strength curve; may not be stronger in the strongest position, but are stronger than average near extension. Which usually means that they are what we call a type G (general) subject; produce strength increases from exercise even in un-worked ranges of movement. People with an initial very low level of strength near extension are usually type S (specific) subjects; do not produce strength increases outside the worked range of movement ... may even lose strength in the un-worked range of movement while gaining strength in the worked range of the same movement.

Both type G and type S subjects produce full-range strength increases when worked with full-range exercise; so there will be less difference in the shapes of the strength curves when properly-trained individuals are compared, but there will still be some difference.

With the quadriceps muscles, you usually have another leg for comparison purposes. When the strength in both legs is the same to within three or four percent, and when the shapes of the strength curves produced by both legs are nearly identical, then you have probably done everything that is possible as a result of exercise. Regardless of the shape of the final curves.

Testing of spinal functions in extension, or in rotation, produces a normal strength curve that is a straight line; so in these cases you have a normal shape for comparison purposes; any meaningful deviation from a straight line is an indication of abnormality. And you have a known target for evaluating rehabilitation; the shape of the curve will tell you when normal function has been restored. With torso-rotation and cervical-rotation testing you have the additional advantage of being able to compare the right side to the left side. Abnormal strength curves produced during spinal-rotation testing are seldom duplicated in both directions of movement.

A comparison of a fresh strength curve to an exhausted curve (following exercise) provides two important sources of information; if the shapes of both curves are consistent, then you are dealing with a cooperative subject; if not, then you should suspect malingering. Secondly, the loss of fresh strength from the exercise tells you the fatigue characteristics on an individual basis.

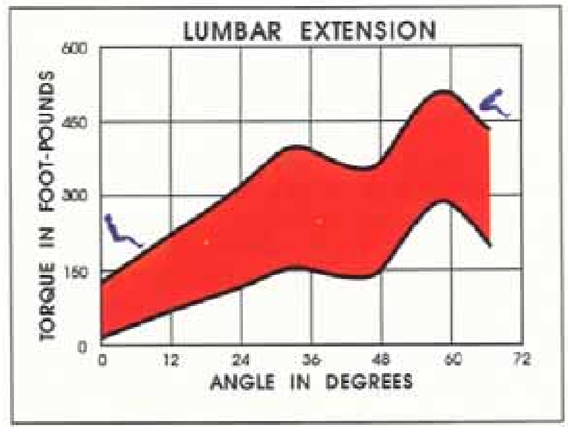


FIGURE 5-6 Fresh and exhausted levels of strength showing the same abnormal shape; clear proof of abnormality. The level of fatigue produced by brief and relatively light exercise indicates a high percentage of fast-twitch fibers in the lumbar muscles. The red area shows fatigue produced by only five repetitions of an exercise with a low level of resistance.

Controversy on the subject of muscular fiber type has been ongoing for the last twenty years, and no end is in sight; but for the purposes of rehabilitation, almost all subjects can be placed into one of only three categories, fast-twitch, slow-twitch, or mixed fiber type. Fast-twitch subjects are usually stronger than expected, based on sex, age, size and previous exercise experience, but have very little endurance; usually have a low tolerance for exercise, should not be exercised frequently or with high-repetition exercise.

Mixed fiber subjects usually show an average level of strength; will generally produce best results from exercise if worked two or three times each week, using a schedule of from eight to twelve repetitions.

But atrophy is selective; fast-twitch fibers atrophy faster and to a greater degree than other types; so an initial appearance of fiber type may be misleading. When first tested, many patients will show a normal level of fatigue following exercise. But as strength increases, fiber type may appear to change; having increased strength to a high level, they may show strength curves, produced much flatter curves. the fatigue characteristics of fast-twitch fibers. But this is not an actual change in fiber type; instead, indicates the reactivation of atrophied fast-twitch fibers.

Since fiber type is usually related to tolerance for exercise, such apparent changes in fiber type are critical during rehabilitation; when this occurs, the number of repetitions used in the exercise should be reduced, and the frequency of exercise should also be reduced. With lumbar-extension exercise, fast-twitch subjects may produce the best results when exercised only once every two weeks; and should never be exercised more frequently than once each week. Do not require more-frequent exercise, and sometimes cannot tolerate more-frequent exercise. A few subjects produce better results when exercised only once every three weeks.

One of the members of our research staff loses strength if exercised once each week, maintains an existing level of strength (but does not gain) if exercised once every two weeks, and gains strength only when exercised once every three weeks. A very low tolerance for exercise.

Strength increases are not always proportionate throughout the full range of movement; so the shape of the strength curve may change by becoming flatter, the initial ratio of strength from the strongest to the weakest position may be reduced. In lumbar extension, an initial ratio of 15 to one is not rare, strength in the flexed position may be 15 times as high as it is in full extension. But having increased strength as much as possible throughout the full range of movement, the final ratio will usually be 1.4 to one, strength in the flexed position then being only 40 percent higher than strength in full extension. An ideal ratio.

These ratios being applicable only to functional strength of the lumbar-extensor muscles; true muscular strength, NMT, will usually show a flat curve with a properly trained subject; strength will be the same in every position throughout a full range of movement. Until that ratio has been produced by exercise, you have a clear indication that additional strength increases are possible, and this usually means that strength near full extension has not yet reached a possible level. During the final eight weeks of a twenty-week study at the University of Florida, the subjects increased their strength in the flexed position by an average of only one percent, while increasing percent. The additional weeks of training changed the shape of their strength curves, produced much flatter curves.

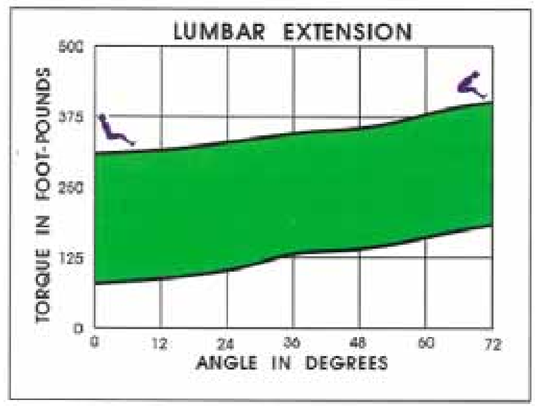


FIGURE 5-7 Peak level of functional strength following several months of isolated exercise; exercise that increased strength in the flexed position by 117 percent strength in full extension by 300 percent. The green area shows increases in functional strength.

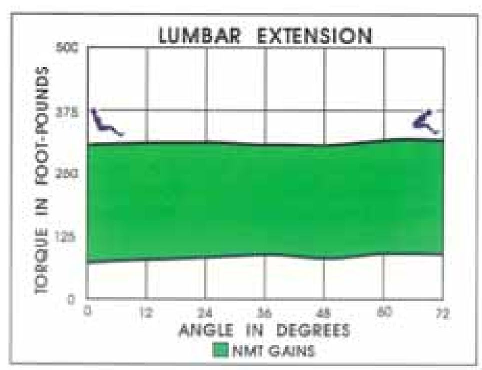


FIGURE 5-8 Corrected for the errors produced by nonmuscular torque, these curves show true levels of strength of the same subject, Figure 5-7. The green

area showing changes in true strength, NMT. True strength in the flexed position increased by 251 percent, compared to the change of 117 percent in functional strength; while true strength in full extension increased by 280 percent, compared to the change of 300 percent in functional strength. Judging strength increases by changes in functional strength in this case would produce errors varying from a low of 2.7 percent in one position to a high of 53.4 percent in another position.

At his final level of true strength, this subject produced an almost perfectly-flat curve of torque; throughout the range, his average true torque was 318 foot-pounds, with a low of 309 and a high of 327 foot-pounds; flat to within a margin of error of only 2.83 percent. An ideal ratio of torque.

Observing the changes that occur in strength curves during rehabilitation not only tells you exactly what results have been produced, but also provides information regarding additional improvement; shows you areas that still need improvement, and tells you how much improvement can be reasonably expected.

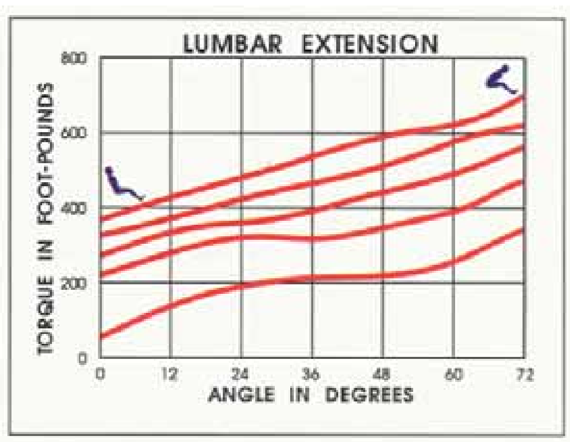


FIGURE 5-9 Five tests of fresh functional strength conducted over a period of five months. While the general trend was a slower rate of strength gains near the end of that period, a comparison of these curves makes it apparent that strength increases were not always consistent throughout the full range of movement. From the first test to the second test, strength increases were greatest near full extension; but from the second test to the fifth test, increases were greatest near the flexed position. And even at this relatively high level of strength, the ratio of strength from the flexed position to the extended position was still not proportionate; a clear indication that he still had the potential for additional increases near the extended position.

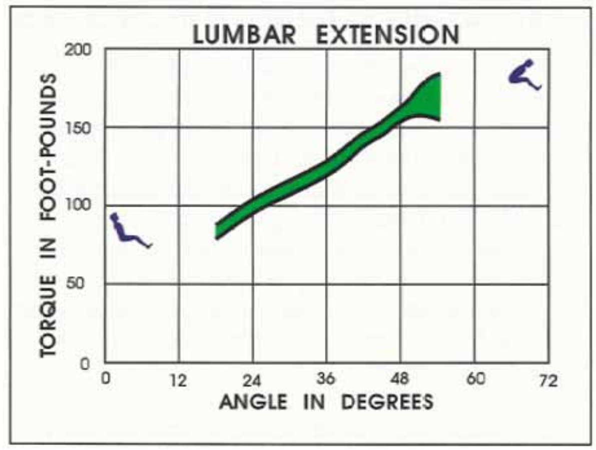


FIGURE 5-10 Two tests of fresh strength conducted about eight minutes apart; no exercise was performed between these tests. The first test produced the lowest curve; during the second test, he was stronger in every position tested, a slow-twitch fiber response. Having a limited range of movement, this subject was tested in only five positions; the first position tested was 54 degrees forward from normal full extension, and in that first tested position the subject did not produce a true level of maximal torque, was probably afraid to produce a maximum effort in that first tested position.

A failure to cooperate that was clearly established by his results in all other positions during both tests, and by the fact that his second test in that position was much higher. Given a maximal effort in that first position, his two curves would have been parallel in every position. Some subjects will show such hesitation in the first one or two positions during an initial test, but will usually produce true curves during later tests. This subject's movement is limited on both ends of the range as a result of ankylosing spondylitis.

EVALUATING STRENGTH INCREASES

Gains in strength are usually evaluated by comparing the increase in strength to the initial level of strength, and then expressing the improvement as a percentage of the starting strength; if the initial level was 100, and the strength following rehabilitation was 150, that would be a gain of 50 percent. But using this system of evaluation can be misleading; sometimes giving the impression that gains in one area were far better than gains in another area, when the actual gains were consistent throughout a full range of movement.

Six years ago, a study group of normal men increased their starting level of strength in the flexed position by an average of 87 percent, while increasing strength in full extension to a much greater extent; which gave the impression that their strength increases in full extension were much greater than in the flexed position. And, as a percentage of their starting level of strength, gains in full extension were much greater.

But when the actual increases in every position throughout a full range of movement were compared, the gains were very consistent; the average increase in the seven positions tested was 268 foot-pounds, with a low of 249 and a high of 297.. .percent above the average, while the lowest was 7 percent result .

Using the percentage method, it would appear that strength increases in full extension were more than five times as high as in the flexed position, while the true difference was less than 20 percent. So it may be better to evaluate strength gains by comparing the actual increases in each position, without regard for the percentage of initial strength.

PROBLEMS WITH NORMATIVE DATA

With knee pathology, the usual availability of a normal leg for comparison purposes provides an advantage during rehabilitation, gives you a standard for judging the progress of the injured leg. With torso rotation and cervical rotation, the right side can be compared to the left. But you have nothing to compare, no standard for judgment, when dealing with the most critical functions in spinal pathology, strength and range of movement in flexion/extension.

The most practical solution involves using each patient as a standard for judging their own improvement during rehabilitation. If they are improving, then you are moving in the right direction.

Normative data has been established in many areas of medicine, but trying to compare a subject with spinal pathology to averages is frequently misleading. Because an individual is different, compared to average, does not mean that they are abnormal, and even if abnormal, this is not always proof of pathology. The slow-twitch subject mentioned in an earlier chapter, following twenty-seven weeks of exercise, was still only slightly above average strength, which would indicate a relatively poor result if compared to average. But when compared to himself, his results were very good, an increase of 877 percent in strength in the extended position. His very low level of initial strength, and his relatively low level of later strength, were both results of his fiber type; comparing such a subject to average is misleading.

During research conducted to determine the best frequency for exercise of the lumbar-extension muscles, six large groups of subjects were compared ... one group, the control group, performed no exercise, but was tested before and after the twelve-week period; showing no change in strength, the expected. . a second group exercised only once each two weeks . . . a third group exercised once each week ... a fourth group exercised twice weekly ... a fifth group three times weekly; these groups using dynamic exercise ... and a sixth group was exercised once each week with a static modality.

A comparison of the five groups that exercised indicated no apparent difference, all exercised groups gained; and, as groups, they gained to the same degree. It did not appear to matter whether they worked only six times within a period of twelve weeks or worked as much as thirty-six times during

But looked at individually, the amount of work did matter. One of the subjects in the three-times weekly group lost strength from overwork. This subject, a very athletic woman, was placed in her group on a random basis, which was a mistake; exercised less frequently she would probably have produced large gains in strength instead of the loss actually produced. During her initial tests she displayed a fast-twitch response to exercise, a high level of fatigue from brief exercise; but at the end of the twelve-week period, she showed a slow-twitch response, very little fatigue from exercise. An apparent change in fiber type that resulted from overuse atrophy.

Like most athletic subjects, she was determined enough to continue with the program in spite of steady losses in strength; losses that were obvious from the fact that she was repeatedly forced to reduce the level of resistance in order to perform the desired number of repetitions. By the end of the program she had lost a large part of her starting level of strength, and appeared to have changed the fiber type in her lumbar-extension muscles. Trying to judge this subject by a comparison to average would be a mistake.

Several years ago, to determine true range of isolated lumbar-spinal movement, we X-rayed a large number of subjects in flexion, in lordosis, and in extension. Average range proved to be 72 degrees, with some variation on an individual basis; but one subject with a range of 70 degrees, which would appear to be normal if compared to average, proved to be grossly abnormal. Three of his lumbar joints had spontaneously fused and showed no relative movement, while the two unfused joints each produced more than twice a normal range of movement. Evaluated on a basis of his full-range movement, he would appear normal; while the true state of affairs clearly indicated a gross abnormality.

A former linebacker with the Chicago Bears visited us recently, bringing his oldest son, a college football player; while here, we tested the strength of their quadriceps muscles, with surprising results. His football career was ended by a knee injury that still gives him pain and greatly-reduced function. But the strength of this injured, obviously atrophied, leg was still much higher than the strength of his son's normal leg. A difference in strength produced by different fiber types in their quadriceps muscles. Even atrophied, he still showed a high percentage of fast-twitch fibers in these muscles, while his son has a high percentage of slow-twitch fibers.

SUDDEN MOVEMENT

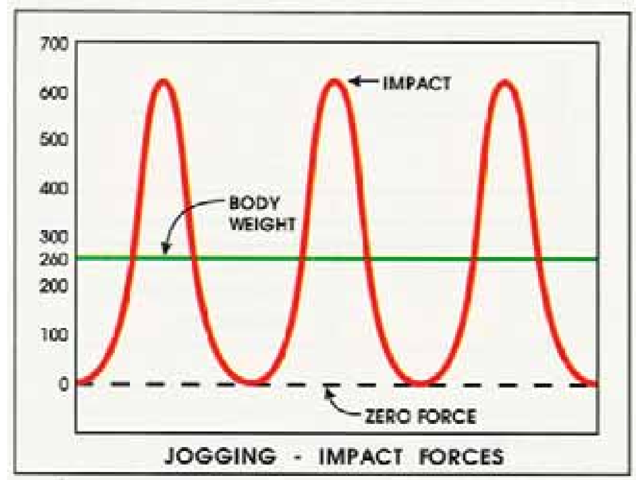


FIGURE 5-11 The fact that the level of resistance in an exercise remains constant does not mean that the level of force imposed upon the subject remains constant. This figure illustrates the levels of force involved during jogging in place. The lowest horizontal line shows a zero level of weight (force), the higher horizontal line shows the bodyweight of the subject, 260 pounds, while the peaks and valleys shown by the curving line show the changes in force resulting from movement while jogging.

Standing still, the subject is exposed to a force equal to bodyweight, 260 pounds, 130 pounds of force on each leg. But while jogging, the level of force is increased to more than 600 pounds, and all of that is imposed upon only one leg; the force is increased by more than 300 percent. High levels of force caused by impact, even in a relatively low-speed activity.

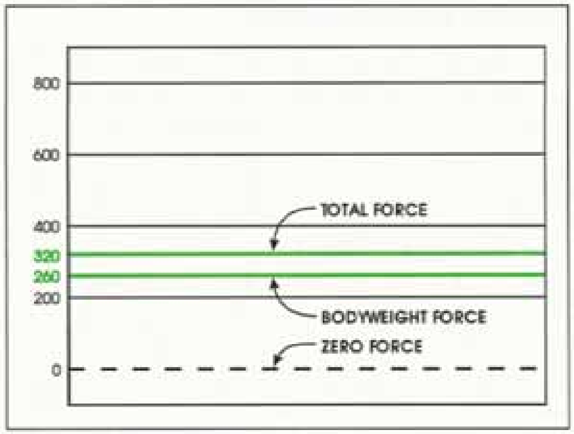


FIGURE 5-12 The lowest horizontal line shows a zero level of force, a higher horizontal line shows bodyweight, 260 pounds of vertical force, and the highest horizontal line shows the resulting force when the subject is holding a 60 pound barbell while standing motionless, 320 pounds of force.

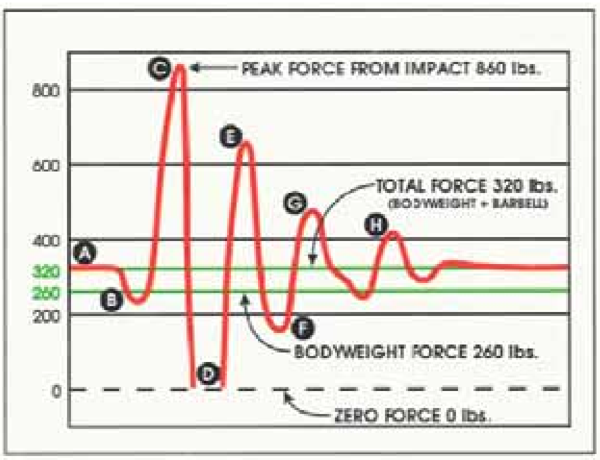


FIGURE 5-13 But when the subject lifts the barbell with sudden movement, the resulting forces are changed to an alarming degree; changes in force shown by the red line of force on this chart. Prior to the start of movement, in the place identified as A on this chart, force remains proportionate to weight, but just prior to the upwards movement of the barbell, the line of force drops below the actual level of force, marked as B on this chart; this initial reduction of force being produced by so-called PRE-STRETCH, when the barbell is permitted to drop a short distance immediately prior to the start of the upwards movement. This pre-stretch is an instinctive action prior to a maximum effort that produces a higher level of force in the following contraction.

But immediately following this initial drop in force, the level of force increases suddenly, and to a very high level; in this case, to a maximum level of 860 pounds, which means that the force produced by the barbell is ten times as high as its weight, adding 600 pounds to the force of bodyweight, a position marked as C on this force curve.

Then, having reached this high level of force, the downwards force on the subject is suddenly reduced to less than zero; less than zero because, at that point in the movement, marked as D, the barbell is lifting the subject into the air as a result of kinetic energy, and no force is being imposed downwards on the subject. But this upwards movement of both barbell and subject does not continue very long, and when they come back down the result is the wildly and suddenly varying levels of force shown by the curving line in the positions marked as E, F, G and H.

Such great variation in force is a result of impact forces produced by sudden movement; dangerous levels of force that are not required for any worthwhile purpose; force that can be avoided by slow, smooth movement.

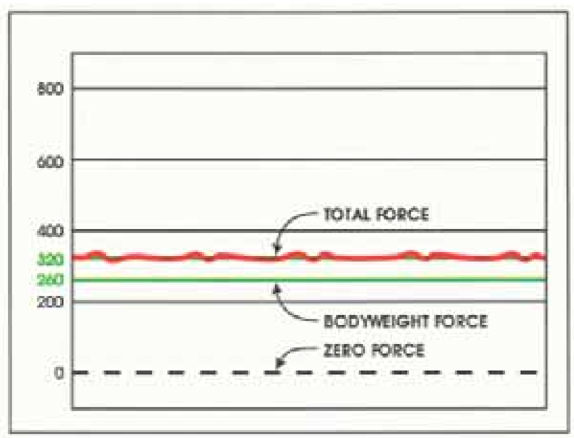


FIGURE 5-14 This chart shows the variation in force produced when the same lift was performed with slow, smooth movement instead of sudden movement. While there is still some slight variation in force, indicated by the curving line moving slightly above and below the highest horizontal line of force, it is obvious that such force changes are of no real importance. Compare force changes shown here to those shown by Figure 5-13.

In spite of the results of sudden movement against resistance, some people have been recommending sudden movement during exercise for the past twenty years; to no good purpose. When in doubt about the proper speed of movement during exercise, move slower; it is impossible to move too slowly during exercise; but it is easy to move too fast, with results like those shown above.

All you are trying to do during exercise is to expose the muscles to known resistance for a relatively brief period, in order to produce the desired level of fatigue within a reasonable length of time. Any force above the minimum required to produce the desired level of fatigue adds nothing of value, but does reduce the safety of the exercise.

Injury during exercise comes from only one source, a force that exceeds the coexisting level of structural strength; so keep the force as low as possible consistent with the existing level of strength; work within the limits of functional strength, do not try to determine the limits of structural strength.

MOTIVATION

Regardless of the potential value of the equipment, the subjects using it will not produce good results without motivation; compensation payments, litigation, and other factors can remove the required motivation.

The subjects involved in our first study group (mentioned in an earlier chapter) were all members of our research team; all of them were highly motivated, and they worked very hard ... and their results were outstanding. No group of random subjects used in later studies did as well on the average. Some individual increases in strength have been even better than those shown by any member of our first group, but the average strength increases were not as high. Motivation, or a lack of motivation, being responsible for this difference.

This is an important subject that needs to be clearly understood. But given a little experience, it becomes easily possible to recognize patients that are not motivated.

TESTING RECOVERY ABILITY

Another important factor during rehabilitation is recovery ability; some subjects recover from fatigue caused by exercise in a matter of minutes, while some do not even start to recover for a period of several days. Recovery tests involve only a test of static strength throughout a full range of movement; a test that should be conducted about five hours after a test of fatigue characteristics. The subjects to look for here are those that do not show full recovery after five hours of rest. By that point, their strength should be back to the fresh level shown at the start of the earlier procedure.

If full recovery is not indicated after five hours of rest, then a following recovery test should be conducted two days later; if full recovery is still not complete, this indicates a low tolerance for exercise and the subject should not be exercised more often than once each week, and then only with a relatively low number of repetitions, from eight to ten repetitions. Some few subjects will not make gains in strength if exercised more frequently than once every third week And subjects that do best on a schedule of one exercise every second week are common; are usually subjects with a high percentage of fast-twitch fibers.

WHAT TO EXPECT FROM EXERCISE

The potential for muscular size, and the potential for both muscular strength and functional strength, and these are different factors, varies widely on an individual basis, on the basis of age, on a basis of sex and on a racial basis. The result being that some people have far more potential than others.

Potential for muscular size is determined by genetic factors; is largely determined by the relative length of the muscle-belly compared to the distance from insertion on one end to the insertion on the other end. Long muscle-bellies and short tendons provide the potential for unusual degrees of muscular size; while short muscle-bellies and long tendons mean a lower than average potential for muscular mass. Some people can build very great muscular mass, and some cannot; they lack the potential for great muscular size.

The functional strength of an individual is determined by several factors; the size of the muscles, the type of fibers the muscles have, the relative length of the limbs and thus the leverage advantages or disadvantages, short limbs being a great advantage for a weightlifter but a disadvantage for a basketball player.

But given an advantage of leverage, and with large muscles, some people are still not very strong; but not because there is something wrong with their muscles;

this problem is usually a result of the fact that such an individual does not have the type of muscle fibers required for great strength, has fibers intended for endurance. So the fact that somebody else reached a certain level of strength or size does not mean that you can too, nor does it mean that the style or amount of training that they used will be right for you.

But there are things that you can expect; you can expect to increase your strength from its starting level if you have never performed exercise for this purpose; you can expect to increase your muscular size; you can expect to increase your flexibility to a marked degree in some movements; and if you continue with exercise for several years you can expect to increase the size of your bones; and you can expect to produce all of these very worthwhile results without hurting yourself in any way, if you exercise in accordance with the instructions offered in this book.

ONE. TYPE OF RESULTS. Expect your muscular size and strength to increase steadily and rather quickly; six months of regular exercise may increase the strength of your muscles to twice the starting level for a previously-untrained individual. Muscles that you have never used to a meaningful degree will respond faster, while those that you have used will respond slower, but they will all become stronger, some by as much as several hundred percent.

Of particular interest for the primary subject of this book, the lumbar spine, most people have the potential to increase the strength of their lumbar-extension muscles to an enormous degree; primarily because most exercises do not work these muscles in a meaningful way, and because normal activities do not provide much work for these muscles. Many people can expect to increase the strength of these muscles by two-hundred percent within a few months, making them three times as strong as they were at the start, and some people can expect twice that degree of results. The neck of the average person usually has the potential for large and rapid strength increases; an area of great importance for preventing injuries, and also of importance for the rehabilitation of neck injuries.

TWO. DURATION OF RESULTS. Some of the benefits of exercise last for years, while some are temporary and are lost if the exercise is stopped entirely; in general, the longer you maintain a high level of strength, the more you will retain after you quit the exercise that increased your strength in the first place.

If your starting level of strength is 100, and if you quickly increase it to 200, and then quit exercising entirely and return to your normal activities that were performed before starting the exercise, your strength will not remain at a level of 200, but it will not drop back to 100; part of your strength increase was permanent. Increasing the strength of your lumbar muscles to a high level will reduce the chance of a later back problem to at least some degree for the rest of your life, even if you stop the exercise after reaching a high level of strength.

But if you maintain that high level of strength for several years by continued exercise, then you will not lose as much when you quit the exercise; you may lose 80 percent of a strength increase that was maintained only briefly, while you would probably lose only 50 or 60 percent of a strength increase that was maintained for several years. Secondly ... having increased the strength of a muscle to a significant degree, and having then quit exercising and having lost a large part of the increase, the next time you start exercising the previous level of peak strength will be produced more rapidly; the body seems to retain a memory of where it has been, and will reach a previously-existing level of strength much faster than it did the first time.

THREE. BI-LATERAL EFFECTS AND INDIRECT EFFECTS. In spite of the fact that most people are Type S, meaning that the results of their exercise are largely confined to the part of a muscle that is exercised; it is still true that hard exercise for a normal right leg will help to reduce the atrophy of an injured left leg that is immobilized in a cast; without such bilateral effect, you might lose 70 percent of the strength of the injured leg, while with such effect you may lose only 50 percent of the strength of the injured leg. A useful bit of knowledge for people working with injuries of the limbs.

Also… heavy exercises for the large muscles of the body produce at least some degree of size and strength increases in other, smaller muscles even when no exercise is performed for these smaller muscles. The value in rehabilitation should be obvious; work all of the muscles of an injured individual that you can; this will not only increase the strength of the exercised muscles but will help to prevent some of the atrophy that would otherwise result in the injured body part.

Soft tissue *injury* results *from failure of* collagen *fibers. Injuries fall* into *one of two categories; microtrauma resulting from overuse and macrotrauma resulting from the* imposition *of a force that exceeds the structural strength of the* tissues. *Following injury, healing occurs in three* stages; inflammation, *repair and remodeling.*

Soft tissues *respond to recent use, are* changing *constantly, growing stronger or becoming weaker. Even two* weeks *of* disuse will *result* in a *meaningful loss of soft-tissue* struc*tural* strength, *together with* metabolic changes. *Full recovery from two* weeks *of* immobilization may *require* as much as six months *of rehabilitative exercise. Perkins (Journal of Bone and Joint Surgery, 35B:521-539, 1953) noted: If not immobilized, an injured shoulder* will *regain* a full *range of motion* within *18 days; but f immobilized for 7 days, recovery requires 52 days; immobilized for 14 days, recovery requires 121* days; *immobilized for 21* days, *recovery requires 300* days.

Immobilization *produces* losses in bone mass, *and even a few* weeks *of immobilization may produce* losses in *bone* mass *that require a period of several years for full recovery.*

In 1859, in The Origin of Species, Charles Darwin noted: In the domestic duck *the bones of the* wing weigh less and *the bones of the leg* weigh *more* in *proportion* to the *whole skeleton* than *do* the same *bones in the* wild *duck. He attributed* these variations *to the domestic duck's reduction in flying* time and *increased* walking *time compared to their wild duck ancestory.*

CHAPTER 6
MEANINGFUL TESTING OF SPINAL FUNCTION

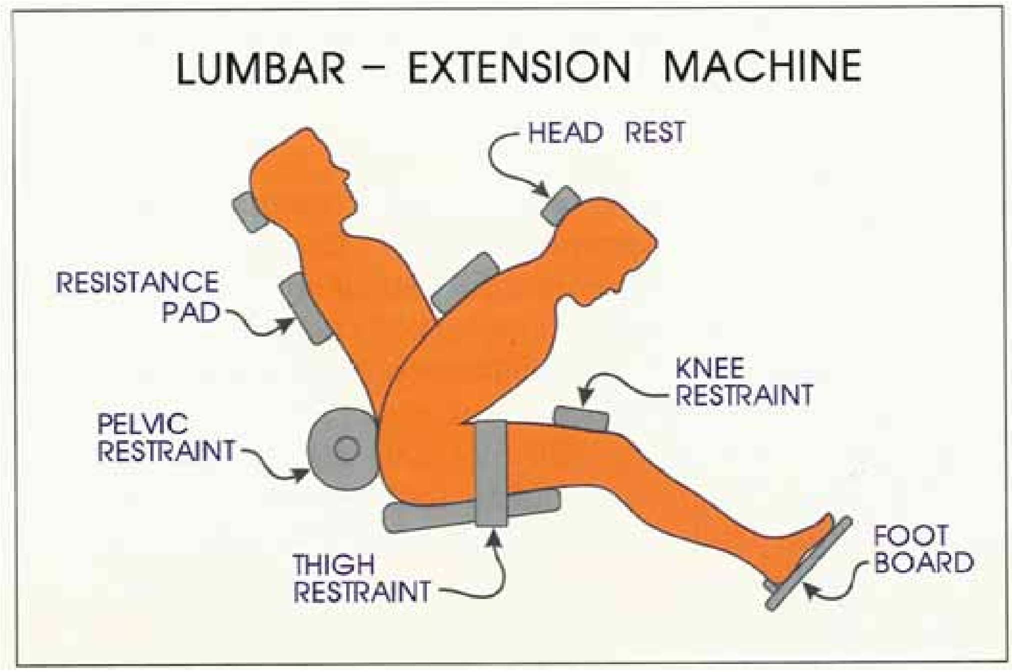


FIGURE 6-1 If the pelvis is free to move, it is impossible to produce meaningful tests of lumbar strength or range of motion. If the pelvis can move during strength tests, the measured torque will be a result of the forces produced by three muscular systems, the hips, the thighs, and the lower back; and it is then impossible to determine what part of the measured torque was actually produced by the muscles that extend the lumbar spine.

Pelvic movement during measurement of spinal range of motion (flexion /extension) produces an overstatement of the true range; two recently published studies in SPINE stated that the range of movement varied from a low of 91 degrees, when measured with two inclinometers, to a high of 96 degrees when measured with a B200 (Isotechnologies). Which is an error of at least 19 degrees, or as much as 24 degrees. True lumbar-spinal flexion /extension is normally 72 degrees.

The same studies quoted torso-rotational range of movement that varied from a low, measured with a compass/goniometer, of 54 degrees, to a high of *77* degrees measured with a B200. Which is an error on the low side in both cases. True torso-rotation in this plane is normally 120 degrees. Additional error was involved in the torso-rotation testing by an unknown degree of pelvic rotation; which was unavoidably included in the published ranges of movement.

For meaningful test results, the pelvis must not move; and when restrained in the manner illustrated above, unwanted pelvic movement is prevented, or reduced to such a small degree that it is impossible to see any movement, and all but impossible to measure any movement. During a recent test to determine the degree of pelvic movement that actually occurred during a test of torso-rotation strength, utilizing very sophisticated CADCAM equipment that can measure movements far too small to be seen, the pelvis moved .004 of one degree under load imposed by a very large man during a test of maximal static torque in the subject's strongest position. Four-thousandths of one degree of unwanted pelvic rotation.

Such all-but-total isolation of the spine can be provided in only one manner; bone-to-bone restraint of the pelvis, utilizing the femurs as an important part of the restraining procedure. The true strength of the spinal muscles, or the true ranges of movement of the spine, can be meaningfully measured in no other manner.

In MedX equipment, force imposed against the bottom of the feet (the illustrated foot board) is transmitted by the lower legs to the femurs. Normal tightness of the hamstring muscles with most subjects requires that the legs be flexed about 45 degrees at the knees, so the force from the feet produces resulting forces on the femurs in two directions; if a force of 100 pounds is imposed on the feet, then a force of approximately 70 pounds will be directed towards the pelvic sockets along the midline of the femurs, while another direction of force will attempt to push the knee ends of the femurs upwards, but the knee restraint pads limit upwards movement of the knees.

The thigh-restraint belt thus becomes a fulcrum; an upwards force of 1 pound on the knees becomes a downwards force of approximately 2 pounds on the pelvic ends of the femurs. The result being force on the pelvis from two directions; force pushing the pelvic/hip sockets towards the rear, and force pushing the pelvis downwards.

Located behind the pelvis, the pelvic-restraining pad is mounted on its own axis of rotation, is free to spin around this axis; but in use it should not spin. But it must be free to move, because any movement of this pad during testing or exercise provides a clear indication that unwanted pelvic movement is occurring; which means that the subject is not properly restrained, or if properly restrained, means that the subject is producing a range of movement that exceeds their actual range of isolated spinal movement.

When a subject is properly restrained in the machine, the relationship of the pelvis to the pelvic-restraint pad becomes identical to the relationship of two gears locked together by their teeth; when either one of such a pair of gears rotates, then the other gear must also rotate. Exactly the same thing occurs in this machine; if the pelvis moves, then the pelvic-restraint pad must rotate around its own axis, movement of the pad that can be clearly seen. But if the pad does not move during testing or exercise procedures, then you can be assured that no movement of the pelvis is occurring.

As illustrated above, the pelvis is restrained against counterclockwise rotation, but no attempt is made to prevent clockwise rotation of the pelvis; doing so would be a mistake. If restraining force was imposed against the top/front sides of the pelvis, then clockwise rotation of the pelvis would also be prevented; but providing such total immobilization of the pelvis, preventing movement in any direction, would then make it impossible to determine the true range of isolated spinal movement.

When a subject is first restrained in the machine, the resistance pad is moved to the rearmost (fully-extended) position and locked in place; so that no force from any source, apart from the restraining forces, is imposed upon the subject; then the subject is requested to slowly move forward in the direction of full flexion of the lumbar spine ... and while the subject moves, the therapist should watch the pelvic-restraint pad.

If the subject can move forward into a position of full flexion of the lumbar spine, with no rotation of the pelvic-restraint pad, then they have a full range of normal movement in the direction of flexion; but if the pelvic pad starts to rotate at any point during the subject's movement, this indicates that the pelvis has started to rotate, which means that the subject does not have a full range of normal movement in the direction of flexion.

But if movement in that direction was prevented, if the top/front of the pelvis could not move forward, then a patient might move into a position that exceeded their existing range of spinal movement. So the freedom of the subject's pelvis to rotate clockwise (clockwise in the illustration used above) is an important consideration, a requirement for safe and meaningful procedures.

During tests of spinal extension in this machine, there is no tendency for the top of the pelvis to move forward, so such restraint is not required; during testing and exercise procedures, the muscles of the hips and thighs will attempt to rotate the pelvis towards the rear, in the direction of extension, which provides an advantage rather than a problem; because, by trying to rotate the pelvis towards extension, the muscles of the hips and thighs hold the pelvis tightly against the pelvic-restraint pad, and thus prevent pelvic movement.

The restraint features of the torso-rotation machine (not illustrated here) are very similar to the system above; utilize force imposed upon the feet and redirected through the femurs to the pelvic/hip sockets.

But in this case the purpose is somewhat different; instead of preventing pelvic movement towards extension, the torso-rotation system prevents longitudinal rotation of the pelvis. But in both cases the results are identical: unwanted pelvic movement is prevented, so that true tests of both spinal strength and range of motion can be conducted without the bias that is otherwise introduced by involvement of the hip and thigh muscles, or by movement of the pelvis.

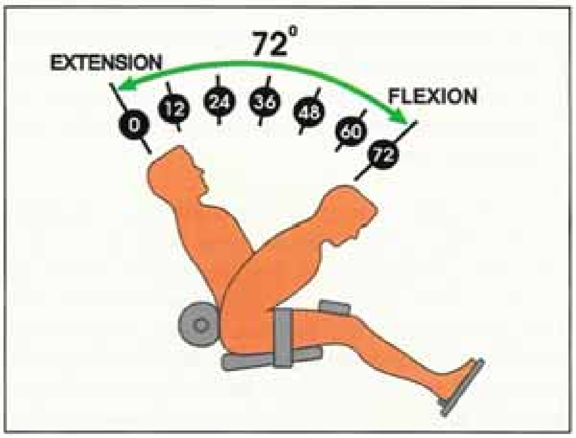


FIGURE 6-2 Testing positions for measurement of lumbar-extension strength. Having established a normal, full range of movement, static tests of torque are then conducted in each of seven positions, at intervals of 12 degrees within 72 degrees of isolated lumbar-spinal movement. While the number of test positions and the exact positions for tests are arbitrary, we normally test in the seven positions shown above.

However, tests can be performed in any or all of twenty-five positions, with three-degree increments between adjacent test positions; thus it is possible to test within one and one-half degrees of any desired position. With limited-range subjects, as many as possible of the above-shown test positions should be used within the possible range of movement on an individual basis.

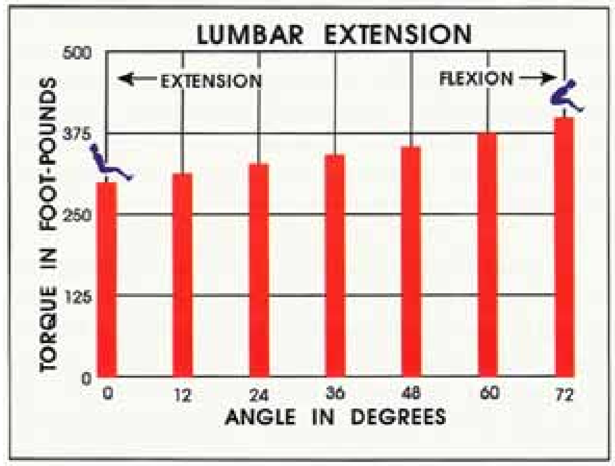


FIGURE 6-3 A bar-graph of tested torque is displayed by the computer monitors as a test is being conducted in each position; this visual feedback of their efforts tends to encourage subjects to produce good results, and also shows the therapist exactly what is happening as it occurs.

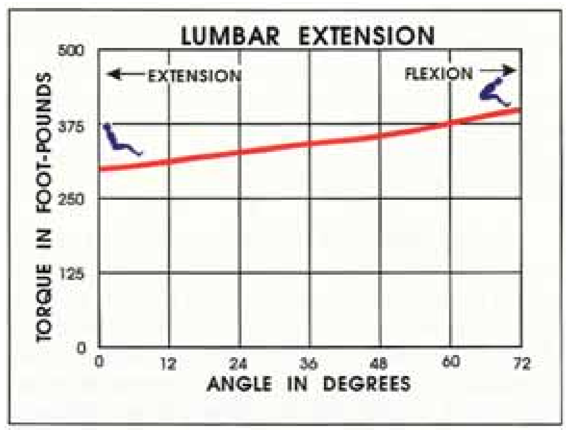


FIGURE 6-4 When all of the desired positions have been tested, the computer will interpolate intermediate positions throughout a full range of tested movement and display the results on the monitor as a curve of strength. Simultaneously, the computer printer will produce a hard copy of the strength curve; together with the actual raw data showing tested torque correlated with the test positions. And all of the results are stored by the computer for later use.

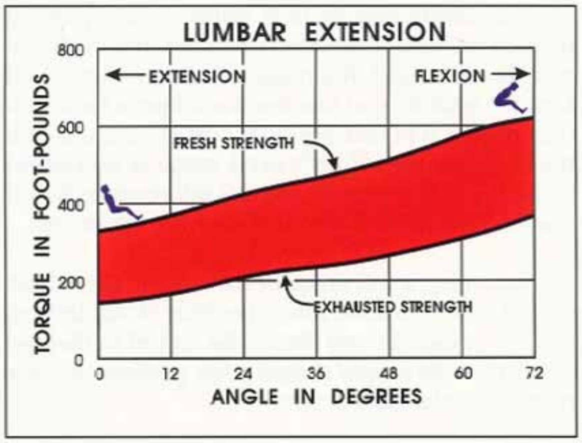


FIGURE 6-5 When a procedure is conducted for determination of fatigue characteristics (muscular fiber-type), the monitor will display and the printer will print both pre-exercise and post-exercise strength curves, together with all of the raw data produced during both tests. Based upon the level of resulting fatigue, compared to the amount of exercise performed during the procedure, the computer will print a hard copy of the significant results produced by the tests; together with suggestions in regard to the frequency and extent of exercise considered best for a subject with similar characteristics.

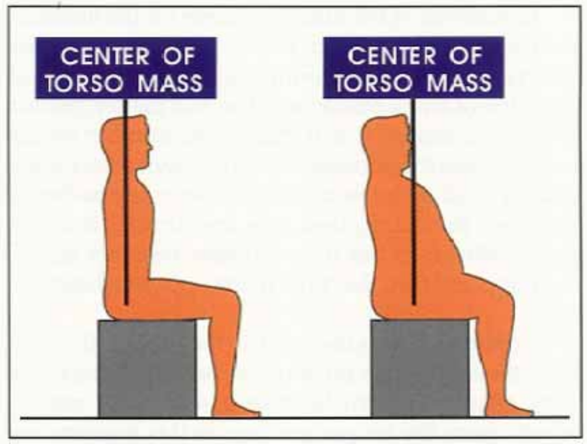


FIGURE 6-6 Because of individual differences in build, the balanced, relaxed position of top-dead center varies as much as 18 degrees; so we must establish STRAIGHT UP, in order to assure that the counterweight is locked into a position that is then STRAIGHT DOWN, 180 degrees out of phase with the subject's midline of torso mass. While the subject remains straight upright, the counterweight is connected to the resistance arm by a locking lever. To assure that the counterweight is straight down while being connected, it is provided with a bubble-level device similar to those used by carpenters.

TESTING PROTOCOLS

Before a subject is seated in the machine, the resistance arm should be moved to the fully-extended position and locked. Once seated in the machine, and properly restrained, the subject should be instructed to relax in an upright position; and then the resistance arm should be unlocked and rotated forwards until the pad touches the subject's back. Since the resistance arm is counterweighted, it will impose no force on the subject during this procedure. The subject should then lightly grip the handles that form a part of the resistance arm and remain relaxed in an upright position. This part of the procedure is preparation for counterweighting of the torso-mass torque; first we must establish a position of top-dead-center on an individual basis, the balanced, upright position in which the subject has no tendency to move either forward or backwards when relaxed.

All of the moving components of the machine, apart from the resistance source, are counter weighted on an individual basis in order to prevent the introduction of unwanted random torque by parts of the machine; and this counterweighting is so carefully provided that even the slight weight of the counterweight-locking lever will throw it out of balance when the lever is in the unlocked position. Thus the need for the bubble level.

After the counterweight is locked into proper position, the subject should move to the most-extended position and relax; whereupon the monitor will display a number that indicates the existing error in the counterweight torque; this may be a positive number, if the counterweight is too light, or a negative number if the counterweight is too heavy.

Located on top of the counterweight, a large wheel provides the ability to adjust the counterweight; while the actual weight of the counterweight remains constant, its input of torque can be adjusted from zero torque to as much as 150 foot-pounds of torque; adjusted by moving the weight up or down in relation to the axis of the machine.

Regardless of the number shown on the monitor, the therapist should turn the crank, turn it in either direction, clockwise or counterclockwise; the original direction of crank movement does not matter; moved in either direction it will change the number on the monitor. But the number should change by becoming smaller; and if the number does become smaller as you turn the crank, then you are turning it in the proper direction; but if the number becomes larger, then stop and turn the crank in the opposite direction.

Continue to turn the crank in the proper direction until the number on the monitor becomes effectively zero, effectively zero because it will never remain exactly zero; the torque readings in this machine are so exact that changes in torque produced by the subject's breathing and heartbeat will be shown. When the number is fluctuating between about .7 (seventenths) of a pound of negative torque and the same magnitude of positive torque, you are as close to a perfectly balanced position as it is possible to produce with a living subject.

The goniometer (angle detector) on the right side of the machine will tell the therapist the position of top-dead-center, and a digital position indicator on the counterweight will show the position of the counterweight in which proper counterweighting was provided. Both of these readings should be entered into the computer record for future use with the same subject.

Barring meaningful changes in body weight, the top-dead-center setting and counterweight position do not have to be remeasured prior to following tests with the same subject. The above procedures are both very simple and easy to perform; can be performed properly in less than one minute, and will probably never have to be repeated with the same subject.

Following these counterweighting procedures, the resistance arm should again be locked into the rear position, and the subject should be instructed to slowly move forward in the direction of full flexion of the lumbar spine; and while the subject moves forward, the therapist should watch the pelvic-restraint pad. This pad is free to rotate about its own axis, but should not rotate; any movement of the pad indicates that the subject has moved forward beyond the true range of isolated spinal movement. The subject's forward movement should be stopped at the point where the pelvic-restraint pad starts to move, if it moves.

The subject should then return to the position reached just prior to pelvic movement, and the therapist should unlock the resistance arm and rotate it forward until its pad touches the subject's back, and then re-lock it in that position. The goniometer will then indicate the subject's exact range of movement in the direction of flexion, and this information should also be recorded by the computer for future use.

Assuming a full range of movement, the subject should move forward into a position of full flexion, and the resistance arm should be locked in that position; then the subject should relax, produce no force from muscular contraction.

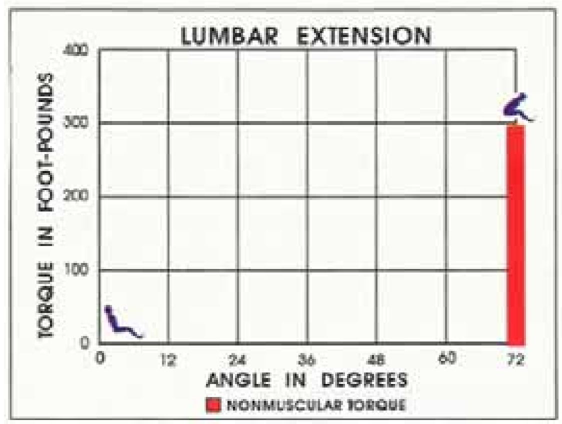


Figure 6-7 Nonmuscular torque produced by a pathological subject: 298 foot-pounds in the flexed position. A large man, even totally relaxed in that position, may show more than 300 foot-pounds of torque on the monitor; torque produced by nonmuscular factors, coming primarily from stored-energy.

While the subject remains relaxed in the first test position, the therapist should move a switch on the machine to record nonmuscular torque; following the test of maximum strength in that position, the computer will subtract nonmuscular torque. The remainder is a measurement of true muscular strength, NNIT, torque actually produced by the force of muscular contraction. The subject should then be tested in six other positions at 12 degree increments. In each tested position, the computer will measure and record both maximum torque and true muscular strength, NMT.

During the test in each position, the subject should be instructed to watch the monitor (a second monitor is provided for the therapist), and as the subject starts to produce muscular force, the monitor shows a rising bar-graph indicating the level of torque being produced.

Effort during the tests should be increased gradually and slowly, sudden changes in force should not be produced; force of muscular contraction should be gradually increased until a maximum level of torque is produced; having produced a maximum level of torque, the subject should then maintain this maximum level for one or two seconds, and then gradually reduce the force until a state of total muscular relaxation is regained. Do not increase force suddenly, and do not reduce force suddenly.

Moving suddenly, jerking during testing procedures, serves no worthwhile purpose; while producing high levels of impact force that may be dangerous.

Initiation of movement, at any speed, while totally avoiding the production of any level of impact force is impossible, but it is possible to reduce the impact forces to such a low level that they are safe; by moving slowly, and by increasing the force of muscular contraction gradually. If the forces of muscular contraction are increased slowly, then any resulting pain will be obvious to the subject long before a maximum level of force has been reached; but with sudden effort, high levels of force are produced so rapidly that damage may result too quickly for the subject to respond properly. Subjects should be instructed to slowly relax at the first sign of pain.

Some doctors and therapists exercise or test patients even when pain is produced by the efforts; but that decision is a matter of individual clinical judgment.

Generally, with a new subject, having completed the test of fresh strength, they are then exercised with an appropriate level of resistance. But just how much resistance is appropriate? This, too, is a matter of clinical judgment; but we usually exercise a new subject for the first time against resistance that is fifty percent of the peak torque produced during the initial test of fresh strength. If peak torque was 300 foot-pounds, then we would use 150 foot-pounds of resistance for the exercise.

But with a new subject, this represents an educated guess at best. Given what appears to be the right level of resistance, some subjects then cannot perform even one full-range movement, while another subject might have performed too many repetitions. These differences are a result of muscular fiber-type; a fast-twitch subject might be so weakened by the test procedure that they then cannot move against the selected level of resistance, while a slow-twitch subject might continue for more than a hundred repetitions if not stopped by the therapist.

Ideally, the subject should be able to perform at least eight full-range movements, but not more than twelve; if they cannot perform eight repetitions, the resistance is too high, and if they can perform more than twelve then the resistance is too low.

During the exercise, movement in the direction of extension should be started slowly and smoothly, and the speed of movement should always be quite slow; upon reaching the most extended position possible, the subject should stop and hold that position against the resistance for one or two seconds, and following that brief pause in the extended position, movement back towards flexion should be started.

During the exercise, the level of resistance is displayed by the monitor, together with the position of the subject; so the subject should watch the monitor throughout the exercise, and will see the moving level of force as it moves towards extension or flexion. As the force approaches the flexed position, the subject should reduce the speed of movement smoothly and start to move back towards extension without allowing the force to drop in the flexed position; after only one or two repetitions during a first exercise session, most subjects can produce very smooth curves of force throughout movement in both directions.

Positive force is displayed as a green line, while negative force is shown as a red line; both lines of force should be almost perfectly straight lines, and can be. Any variation above or below a straight line of force is an indication of jerky movement on the part of the subject; an error that will be obvious to both the subject and the therapist.

391 levels of resistance are provided by the lumbar-extension machine, in increments of one foot-pound, from a minimum of 10 foot-pounds to a maximum of 400 foot-pounds.

For both testing and exercise, the range of movement can be adjusted to conform to any possible range on an individual basis, in increments of three degrees of movement; and the machine will not provide resistance outside the selected range.

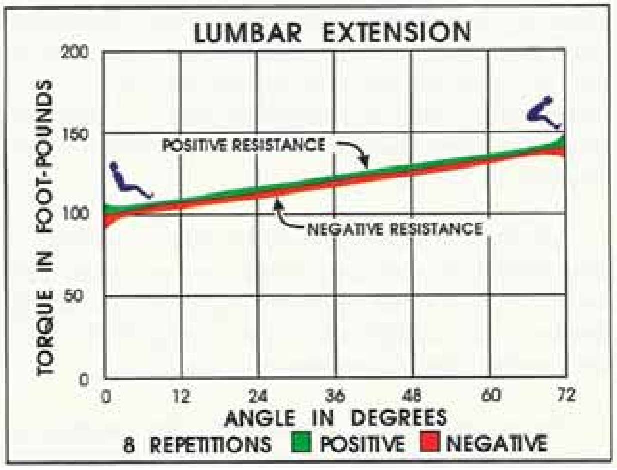


FIGURE 6-8 Levels of resistance involved during eight repetitions performed on a MedX lumbar-extension machine. Both friction and kinetic energy have been reduced to the lowest possible levels in MedX machines, and the result is a source of resistance that is almost perfectly smooth. MedX machines measure the level of effort during testing and provide the selected level of resistance for exercise, but do not impose force on the subject during either testing or exercise.

During testing, the resistance pad is locked in the selected position and cannot move; the subject produces effort and the machine records the level of effort. During exercise, prior to the start of movement, the machine provides no resistance. When moving, resistance is provided that is exactly equal to the level of effort produced by the subject. A level of effort and matching resistance that is selected by the therapist; high enough to provide meaningful exercise but low enough to permit the desired number of repetitions, and always in proportion to the subject's momentary level of strength.

Properly exercised once a week for a period of ten or twelve weeks, most subjects will increase their strength in a position of full extension by at least 100 percent, and many subjects will produce much better results. With the muscles that extend the lumbar spine, more exercise is seldom the solution ... and is sometimes the problem.

TESTING TORSO-ROTATION STRENGTH

FIGURE 6-9 The pelvic-restraint system used for torso-rotational testing is similar to the system used in the lumbar-extension machine; but is designed to prevent pelvic rotation around a longitudinal axis, rather than in the direction of extension. When the torso is rotated, the pelvis will rotate together with the spine if such movement is possible, and this pelvic movement makes it impossible to measure true spinal rotation; so the pelvis must be restrained, and can be.

In order to rotate, the pelvis must push one of the femurs forward while pulling the other femur back; so preventing any movement of the femurs will stop unwanted movement of the pelvis. When properly restrained, any movement of the pelvis is impossible to see and almost impossible to measure.

With no movement of the pelvis, and excluding cervical rotation, a normal, full range of spinal rotation is 120 degrees, 60 degrees to either side of a neutral, straight-forward position. Nearly all of which spinal rotation occurs above T-11; longitudinal rotation of the spine from T-11 through the sacrum is very slight, and impossible to measure with current technology. Meaningful rotation below T-1 I is prevented by the interlocking relationship of the vertebral facets below T-11. A situation that can create problems if not considered; no attempt to stretch should be made in this plane of movement. If the range of movement is below normal, you cannot always tell why the range is limited; trying to increase the range by stretching could thus lead to damage in the facets. So the true range of pain-free movement must be established prior to testing or exercise in this plane. Which involves a very simple procedure.

Once restrained in the machine, the subject should rotate the torso as far as possible towards their right, moving slowly, and moving against no external source of resistance, no EXTERNAL resistance; but there will be some resistance to such movement produced by stored energy. As you move during torso rotation, it is necessary to store energy in order to move; you are stretching tissue on one side of the body while compressing tissue on the opposite side, which will produce internal resistance against continued movement.

At the end of the range of movement, continued movement in that direction may be impossible even though the spine itself is capable of a greater range of movement; continued movement then being prevented because the existing level of strength is identical to the coexisting level of stored energy, thus producing equal and opposite force-, that make continued movement impossible.

Which explains why many patients using this machine increase their range of movement even without stretching; as they become stronger, they can move farther against the internal resistance from stored energy.

Since this movement is performed in a horizontal plane, the usual effects of gravity are not involved, so no counterweighting is required; which makes both testing and exercise procedures easier to perform. But one additional step is required in this machine; having determined the individual range of movement in both directions, the machine must then be locked to prevent any movement beyond that range.

Figure 6-10 A locking system located above the subject limits movement to any desired range, in increments of 6 degrees. Thus locked, it is then impossible for the subject to move past the end of the selected range.

During a strength-test procedure, the subject should rotate to either end of the range of movement and the machine should be locked in that position. With the subject totally relaxed in that position the monitor will show, and the computer will record, the torque produced by stored energy; nonmuscular torque that must be measured and subtracted from z the following level of tested torque in order to determine true strength in that position, NMT. While the level of stored-energy torque in this movement is far less than such torque produced during tests of lumbar extension, it still remains an important factor for meaningful test results.

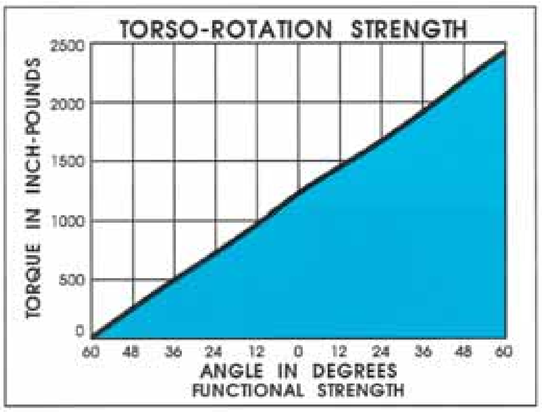


FIGURE 6-11 In his strongest position, this subject produced 2,424 inch-pounds of functional torque; in his weakest position, torque was only one inch pound. Strength in intermediate positions varied throughout the movement range, and the strength curve was nearly a straight line, as it should be.

In his strongest position, this subject's true strength was overstated by only 27 foot-pounds (324inch-pounds) of stored-energy torque, and in the weakest position, true strength was understated by 25 foot-pounds (300 inch-pounds) of stored-energy torque; which is relatively low compared to the level produced in a test of lumbar-extension strength, where it may exceed 300 foot-pounds. But even with this relatively low level of nonmuscular torque, the test results were biased to an enormous degree; with one error exceeding 240,000 percent and another error of 30,000 percent.

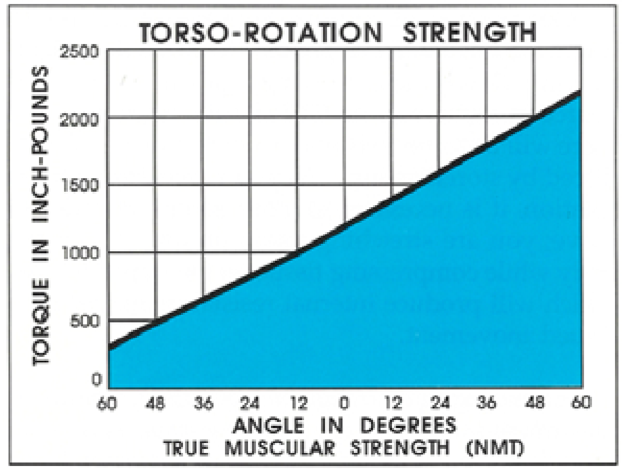


FIGURE 6-12 Corrected for the error from stored-energy torque, the curve of true strength was lower in the strongest position and higher in the weakest position. Peak torque was reduced from 202 foot-pounds to 175 foot-pounds, a relatively small change; but strength in the weakest position was increased from a tested level of only one inch-pound to a true level of 301 inch-pounds, an increase of 30,000 percent.

While an even greater degree of error was corrected in the tested ratio of strength. In the test of functional strength the highest level was 2,424 times as high as the lowest level; an increase in strength of 242,300 percent from his weakest position to his strongest position. A change in functional strength that exceeded 2,000 percent per degree of movement, on the average, throughout the tested range of 120 degrees.

But when this tested strength was corrected for the error from stored-energy torque, the true ratio proved to be seven to one; an increase in strength from lowest to highest of only 600 percent. So the actual increase in strength, per degree of movement, was only 5 percent, rather than the indicated 2,000 percent. But even with a true change in strength of5 percent per degree of movement, the importance of correlating measurements of position with tested levels of strength should be apparent; an error in position of only two degrees might produce an error in tested torque of ten percent, or more.

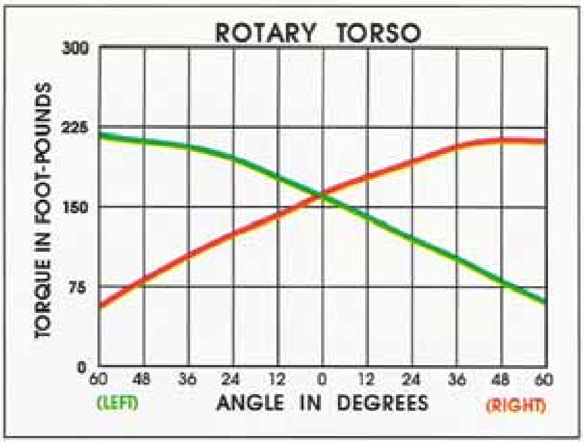


FIGURE 6-13 In the torso-rotation machine, strength must be tested in two directions, rotation to the right and to the left; which would produce test results like the above example if not corrected.

When strength in one direction is compared to strength in the opposite direction, without correction, the crossing of the two strength curves makes it difficult to compare the strength of one side to that of the other side.

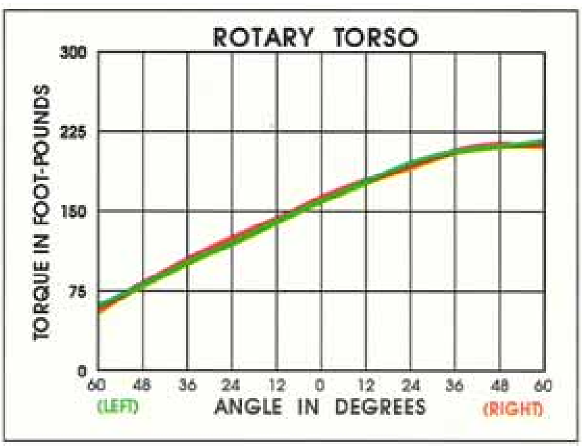


FIGURE 6-14 So the computer corrects for this problem by rotating one of the curves by 180 degrees; so that both curves slope in the same direction, which makes comparison much easier. This ability to compare strength and range of movement in one direction to the opposite direction provides an important capability for judging spinal pathology; normal subjects show little or no difference when the right side is compared to the left, but spinal patients frequently show marked differences.

Research conducted with the lumbar-extension machine established the enormous potential for strength increases in that movement, and we then expected to produce similar increases in torso-rotation; but this did not occur. While strength increases in torso-rotation have been very good, they are not as good as those produced by the lumbar-extension machine.

Which, initially, was a disappointing result; but in retrospect it may have been an actual advantage, because it provides one more indication of the unique nature of the lumbar-extension muscles. It is our opinion that the usual weakness of the lumbar-extension muscles, even in healthy, normal subjects, is the weak link in the musculoskeletal system of the spine; weakness that is probably responsible for a high percentage of spinal problems. It is also our opinion that the muscles that rotate the torso are very important ... second in importance only to the extension muscles.

Testing torso-rotation strength involves tests in a relatively large number of positions, due to the greater range of movement; and since tests must be conducted in both directions of movement, we do not recommend such testing more often than once

every four weeks. But best results in strength increases may be produced by exercising these muscles twice each week, or even three times weekly.

In general, exercise for the lumbar-extension muscles should not be conducted on the same day that exercise for torso-rotation is performed; the level of fatigue produced by some subjects when both exercises are performed on the same day may serve to inhibit strength increases. Exercise does not PRODUCE strength increases, it STIMULATES strength increases; but having been properly stimulated by exercise, following strength increases cannot be produced without the required period of rest between exercise sessions.

CERVICAL ROTATION

Measurements of both strength and range of motion in the cervical spine are conducted using protocols similar to torso-rotation; similar but with some important differences. The level of strength is much lower; so measurement of strength is performed in increments of inch-pounds of torque, rather than foot-pounds. Range of motion is greater; normal range being 168 degrees, rather than 120 degrees. The possibility of exceeding a true range of movement being more critical in the neck than in the torso, range of movement is limited with an infinite number of positions within a finite range.

Smoothness of resistance for exercise being important, the kinetic energy in this machine has been reduced by more than 95 percent below a usual level. Friction also being important, because of the relatively low level of strength of these muscles, it has been reduced to the lowest possible level. Reductions of both kinetic energy and friction are provided by the unique capability of the compound-cam system used in this machine for automatic variation of resistance as movement occurs from a stronger position towards a weaker position. Or vice versa.

Restraint for prevention of unwanted movement of body parts is provided by a system that isolates the cervical spine by anchoring the shoulders, rather than restraining the pelvis. Because movement occurs in a lateral plane, the effects of gravity are not involved; so counterweighting is not required, and error from body-part torque is avoided. Restraint involves only two adjustments; vertical adjustment of the seat, and adjustment of the pad system that restrains the shoulders. The only nonmuscular source of torque is a result of a low level of stored energy; which is measured by the machine and factored into test results by the computer.

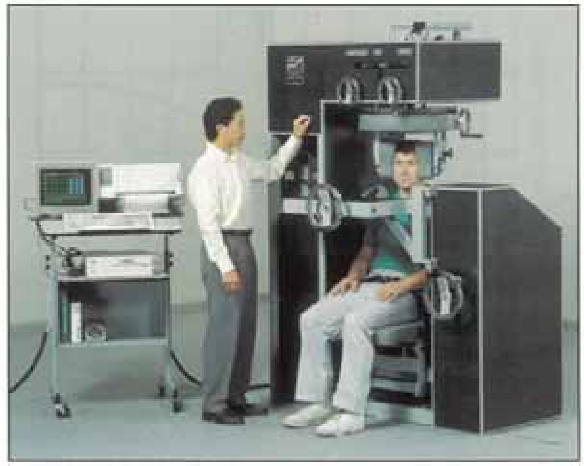


FIGURE 6-15 Because of the greater range of movement, with normal subjects, tests are conducted in a total of eleven positions, in increments of 12 degrees; but with a limited-range subject, tests can be conducted in increments of 6 degrees if desired.

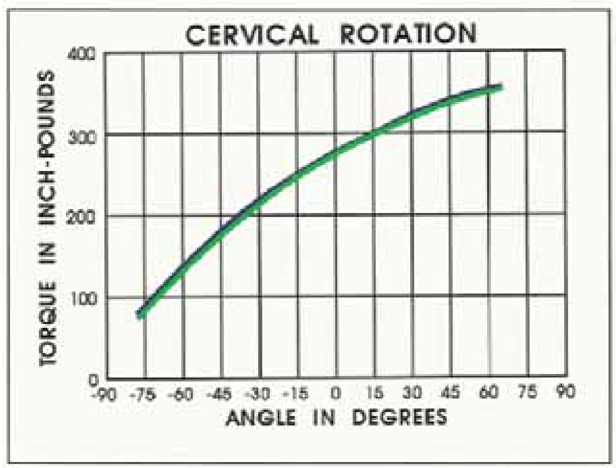


FIGURE 6-16 Research has demonstrated that the muscles that rotate the cervical spine are usually slow-twitch in their fiber type. This test compares the pre-exercise level of fresh strength to the post-exercise level of remaining strength, showing almost no change in strength as a result of fatigue. Research has also established the need for exercise in these muscles; best results in strength increases are usually produced by three weekly sessions of exercise; in this case, more exercise does seem to be more productive, up to a reasonable point.

PROTOCOL FOR TESTING

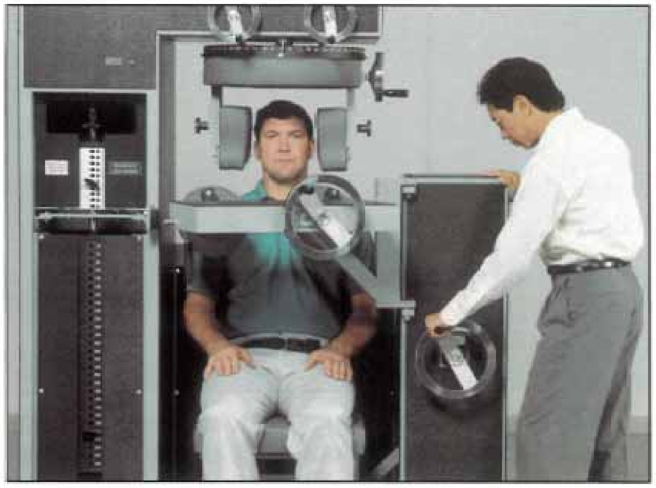


FIGURE 6-17 Vertical adjustment of the seat is required to position the subject's head in relation to the head-restraint pads; primarily to avoid pressure on the ears. Vertical adjustment of the seat is provided by this large wheel; and once the proper position is established, the exact elevation is indicated by a digital position-indicator. Information that should be stored in the computer to avoid later repetition of this step when dealing with the same subject.

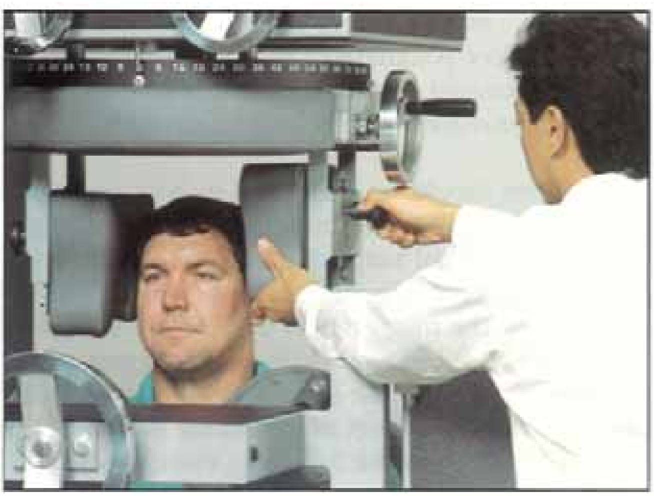


FIGURE 6-18 Additional vertical adjustment is provided by the head-restraint system, if required on an individual basis.

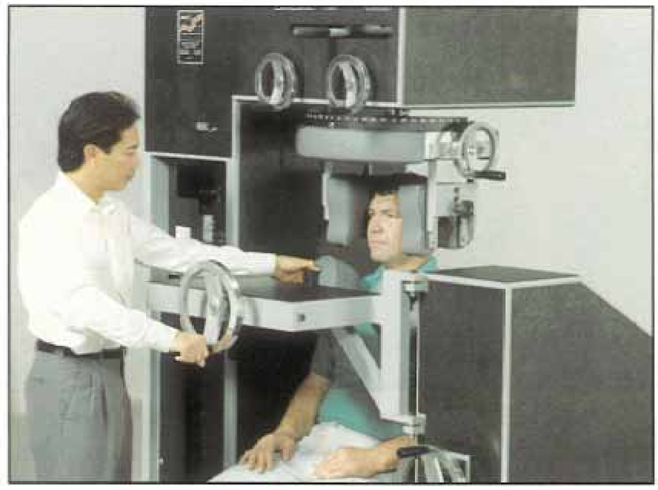


FIGURE 6-19 Unwanted movement of the torso is prevented by restraining the shoulders; adjustment of the shoulder pads being provided by the large wheel shown above.

FIGURE 6-20 Turning this crank tightens the head-restraint pads.

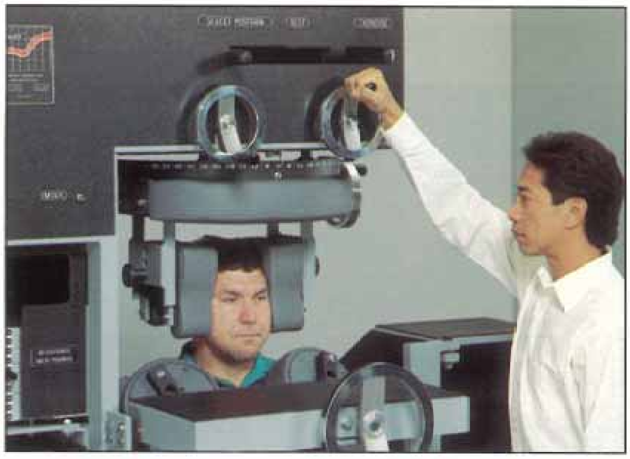


FIGURE 6-21 Seated and properly restrained, in a neutral (straight-forward) position, movement of the head is prevented by the range-limiting system. Initial prevention of movement is required as a first step in the measurement of cervical-rotation range of movement on an individual basis.

FIGURE 6-22 The subject is instructed to rotate their head, first in one direction and later in the opposite direction, producing a very low level of effort; and while the subject tries to turn the head, the therapist turns one of the two large wheels that permit such movement. No force is imposed upon the subject in an attempt to increase the range of head movement; when the subject can no longer produce movement in that direction, the therapist stops turning the wheel, and range of possible movement is thus limited to the subject's exact range. Range limitation should then be provided in the opposite direction.

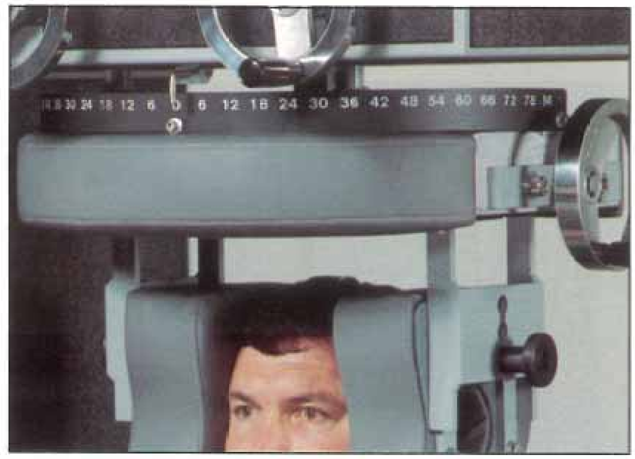


FIGURE 6-23 A large goniometer (angle indicator) is located above the subject's head, and this will show the actual range of movement; while the computer will record the range in increments of one degree. Having established range of movement on an individual basis, static tests of strength should be conducted in several positions throughout the range; tests being required in both directions, rotation to both left and right.

EXERCISE

Exercise is provided with any of 291 levels of resistance . . . from a low of 20 inch-pounds (one and two-thirds foot-pounds) to a high of 600 inch-pounds (fifty foot-pounds), in increments of 2 inch-pounds. Appropriate resistance for any level of strength.

Exercise should be performed in both directions, and should be continued until the subject is unable to complete the initial range of movement against resistance; when remaining range of movement falls 12 degrees below the initial range, the exercise should be discontinued. When a subject is capable of performing 12 movements with the same range involved in the first repetition, the level of resistance should be increased by 5 percent for following exercise sessions.

Speed of movement should be slow, with a brief pause in the position of full contraction of the muscles; sudden or jerky movement should be avoided, but will be displayed by the computer monitor if it occurs, thereby providing the therapist with a clear picture of the actual style of performance of the exercise.

Proper style of performance being important because it provides appropriate levels of resistance throughout a full range of possible movement, and because it avoids unwanted levels of excess force resulting from impact if a jerky style of movement is involved.

CERVICAL EXTENSION

FIGURE 6-24 Normal range of movement is 120 degrees, and testing can be conducted in any of 43 positions, in increments of 3 degrees. Given a subject with full-range movement, testing is normally conducted in eight positions, in increments of 18 degrees throughout the full range.

Since vertical movement is involved, counterweighting of the head must be provided, together with adjustment for individual differences in the upright position of the head.

Isolation of the cervical spine is provided by restraining the torso in a manner identical to the system used in the cervical-rotation machine.

Resistance for exercise is provided at any of 291 levels; from a minimum of 30 inch-pounds to a maximum of 900 inch-pounds, in increments of three inch-pounds (one-fourth of a pound).

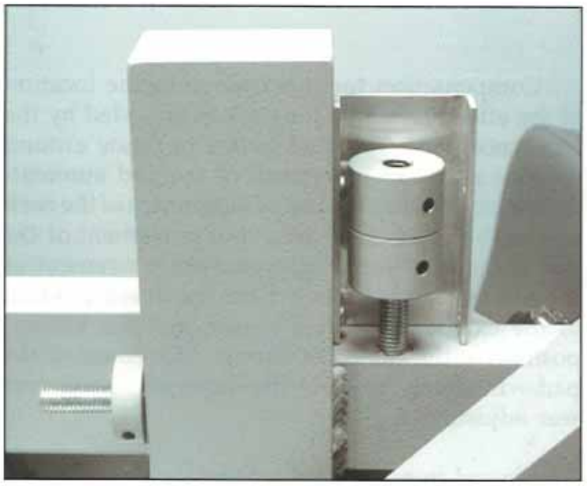
Tests of strength are recorded in inch-pounds of torque, correlated with the positions in which tests were conducted.

Vertical adjustment of the seat is provided to bring the effective axis of the neck into coaxial alignment with the axis of the machine. Since extension of the neck involves movement of several joints, this compound movement produces an effective axis of rotation that is not in coaxial alignment with any one of the individual joints; and since the machine has only one axis of rotation, and because the effective axis of the neck changes as movement occurs, this means that the axis of the machine will never remain perfectly aligned with the effective axis of the neck.

Compensation for this change in the location of the effective axis of the neck is provided by the resistance pad. This pad is free to rotate around its own axis; and movement of the pad automatically compensates for any misalignment of the neck axis with the machine axis. But movement of the pad should be very slight; marked movement of the pad as a subject moves from the flexed position to the extended position means that the vertical position of the subject is wrong. Movement of the pad will clearly indicate the required direction of seat adjustment.

Viewed from their left side by the therapist, if a marked degree of clockwise rotation of the pad occurs as a subject moves towards extension, this means the seat is too high, and if movement occurs in a counterclockwise direction, this means the seat is too low. In either case the seat should be adjusted up or down until very little rotation of the pad is produced by full-range movement of the head.

Having adjusted the seat for proper positioning of the head in relation to the resistance pad, the centerline of the head should be established and the counterweight engaged in that position. Then the mass of the head should be balanced by adjusting the level of torque provided by the counterweight.



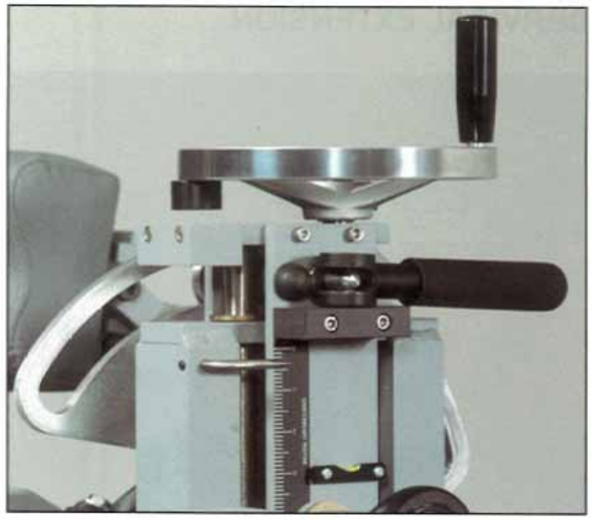


FIGURE 6-25 Apart from the resistance source, every part of the machine that moves is counterweighted to prevent the introduction of random torque from parts of the machine. Then, having been counterweighted individually, all of the moving parts are counterweighted collectively with the counterweight shown here.

And then the counterweight itself is counterweighted in order to compensate for any slightest variation from one machine to another; counterweighted in two ways, to adjust the counterweight torque on an individual-machine basis, and to correct any difference in the centerline of counterweight torque. The two small, round weights mounted on threaded rods provide these adjustments. Balancing procedures that are performed at the factory.

FIGURE 6-26 The wheel located on top of the counterweight for head mass is used for adjustment of counterweight torque, and the weight of the black handle used for adjustments is individually counterweighted by the small weight located directly opposite the handle position; providing a perfect degree of counterweighting even for parts with a weight of only a few ounces.

FIGURE 6-27 When a subject's head is STRAIGHT UP, the counterweight must be STRAIGHT DOWN; so the counterweight must be adjustable in order to compensate for individual differences in the top-dead-center position of the head. Which adjustment is provided. But the exact balance of each part of the machine is so carefully provided that the locking lever of the counterweight assembly will throw it out of balance when this lever is in the unlocked position; so a level device is provided to enable the therapist to produce an exact position of bottom-dead-center (straight down) of the counterweight during the locking procedure.

Such exact counterweighting, together with proper alignment of all related parts of the machine and body parts of the subject, is required to remove random torque that would bias test results. A scale must be balanced before it can provide an accurate weight; and any testing machine must be balanced in a similar manner for the same reason.

CHAPTER 7

SPINAL FUNCTION

Spinal function is not always what it appears to be; true spinal function can be determined only under certain conditions.

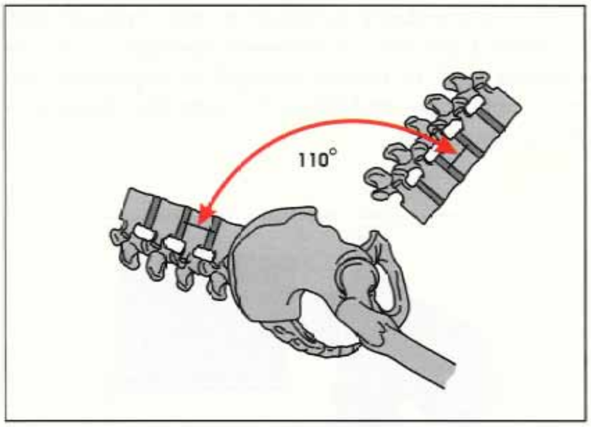


FIGURE 7-1 Back extension can be performed in three distinct fashions; this figure illustrates back extension that involves only hip function. The pelvis moves as a result of the hip and thigh muscles, but the lumbar spine does not change its position in relation to the pelvis. Testing in this fashion tells nothing about the strength of the spinal muscles; and exercise performed in this fashion will not increase the strength of spinal muscles. Both testing and exercise procedures performed in this manner are dangerous; because the spine has reached its limit of movement in the direction of flexion, any force imposed in that posture will tend to move the spine beyond its limit of movement.

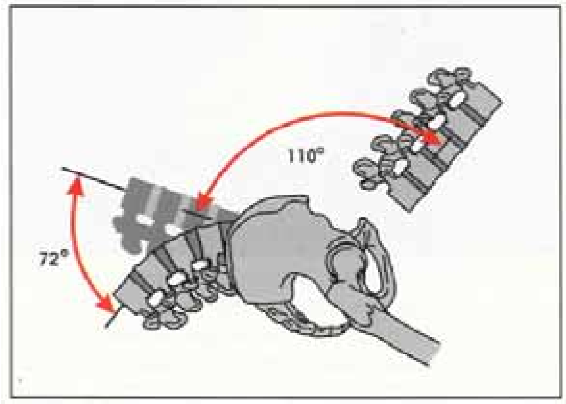


FIGURE 7-2 During the type of movement illustrated here, the pelvis moves as a result of the hip and thigh muscles, while the lumbar spine moves as a result of the spinal muscles. Testing this compound function tells nothing of value about the strength of the lumbar muscles, and exercise performed in this manner has little or no effect upon the spinal muscles. Such exercise will increase the strength of the hip and thigh muscles, while leaving the spinal muscles in a continuing state of atrophied weakness.

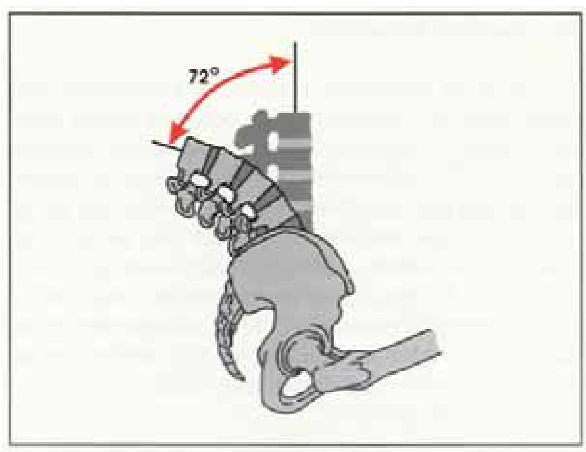


FIGURE 7-3 Meaningful testing or productive exercise must be performed as shown here; the pelvis must not move, and if properly restrained will not move. Isolated lumbar function.

FIGURE 7-4 When the torso is rotated, the pelvis will also rotate if not restrained; and it is then impossible to determine the true range of spinal motion. In order to rotate, the pelvis must push one femur forward while pulling the other femur back, which produces the type of knee movement illustrated here. But pelvic rotation can be prevented by making it impossible for the knees to move; and then the true range of spinal rotation can be measured.

The average range of lumbar-spinal movement in flexion /extension is 72 degrees; while the average range of spinal rotation, excluding the cervical spine, is 120 degrees; almost all of which rotation occurs above T I1. The interlocking relationship of the spinal facets below T 11 limits rotation to such a small degree of movement that it cannot be measured accurately.

All of the muscles in the torso are important, but some are more important than others; a rather common opinion suggests that the abdominal muscles are critical for prevention or rehabilitation of lowerback problems, and these muscles should not be ignored; but the abdominal muscles are seldom the cause of lower-back problems or the solution to such problems. To the degree that muscular weakness is a factor in spinal pathology, the most important muscles are the extensor muscles of the lumbar spine, and the second most important muscles are those that rotate the torso.

Attempts have been made to determine the ratio the extended position. of strength between torso extension and flexion; and claims have been made that this ratio is important. But dynamic attempts to measure this ratio were misleading; biased by torso-mass torque, by stored energy torque, and by muscular friction.

Moving towards flexion, the weight of the subject's upper body increases the torque, while stored-energy and friction tend to reduce the level of torque; any tested result being meaningless.

But when moving towards extension, the weight of the subject's torso, head, and arms reduces torque, with an additional reduction coming from muscular friction, while stored-energy tends to increase the level of torque; again producing meaningless test results. Additional error is produced by impact force that is unavoidably included in any dynamic test. So even if the ratio of extension strength to the coexisting level of flexion strength is important, this ratio cannot be established by tests like those now being conducted.

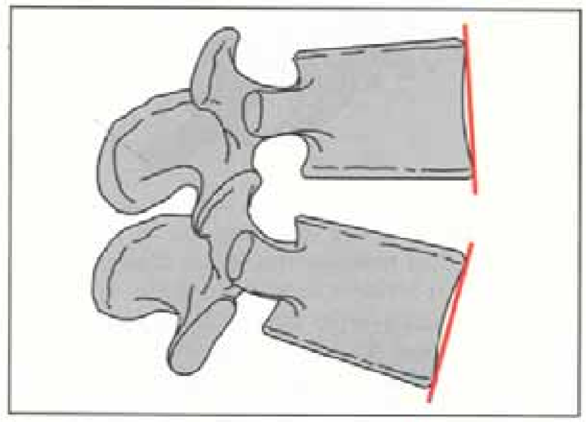


FIGURE 7-5 Even with the use of the most sophisticated imaging technology available, it is difficult to measure the true range of isolated spinal movement; problems resulting from perspective make it impossible to determine the top or bottom of the individual vertebral bodies, and the irregular shapes make it difficult to determine the location of the front surfaces. But by using lateral X-ray pictures in the flexed and extended positions, it is possible to measure this range of movement with a high degree of accuracy. Scribing a thin, straight line on the X-ray picture in the manner illustrated here, a different line on the front of each of the five lumbar vertebrae, will provide a reference for establishing the angular relationship in any position from the flexed position to the extended position.

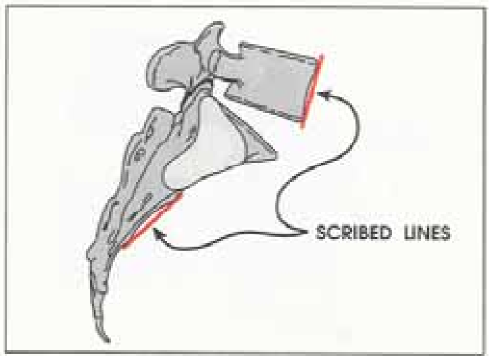


FIGURE 7-6 X-ray pictures of the sacrum are seldom as clear as the vertebrae, but the front face of the sacrum usually has rather distinct points that can be clearly seen on a lateral X-ray picture; so a thin line scribed on the picture as illustrated here will establish a reference point for measuring movement from the sacrum throughout the entire range of lumbar-spinal movement.

STRONG IS A RELATIVE TERM

The first person ever accurately tested for the isolated strength of the muscles that extend the lumbar spine was a very muscular man in his mid-thirties; a man with a twenty year history of hard exercise, including seven years of regular exercise performed with a Nautilus lower-back machine. So we expected him to be strong.

For a period of several years prior to his first test of isolated lumbar strength, we had been testing the strength of his quadriceps muscles (leg-extension), and he was far above an average level of strength in that movement, with fresh muscles could produce more than 400 foot-pounds of torque in his strongest position, with both legs working together. Knowing his level of quadriceps strength, we were surprised when he produced a peak torque of 340 foot-pounds with the much smaller muscles of the spine; considering the relative sizes of the quadriceps muscles and lumbar muscles, it appeared to be impossible for the lumbar muscles to produce that much torque.

But when known levels of torque were imposed on the machine, the error was less than one-tenth of one percent, the machine was accurate. So we then justified his apparently high level of lumbar strength on the grounds of his long history of hard exercise; at the time did not expect to find many other subjects that would be equally strong.

During the next five months he increased the strength of his lumbar-extension muscles to an enormous degree; gains in strength that made it obvious that his initial strength, rather than being unusually high, was actually a low level of spinal strength. Average strength for untrained subjects had then not been established; but when it was established, it turned out that his initial strength was below average for an untrained subject of his sex, age, and size.

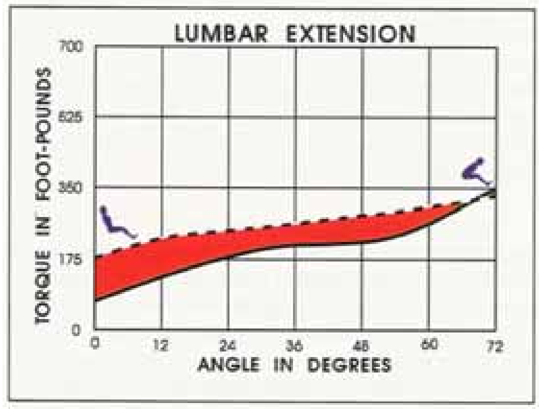


FIGURE 7-7 Initial strength of the subject mentioned above, compared to average strength for an untrained subject. The red area between the two curves shows strength below average.

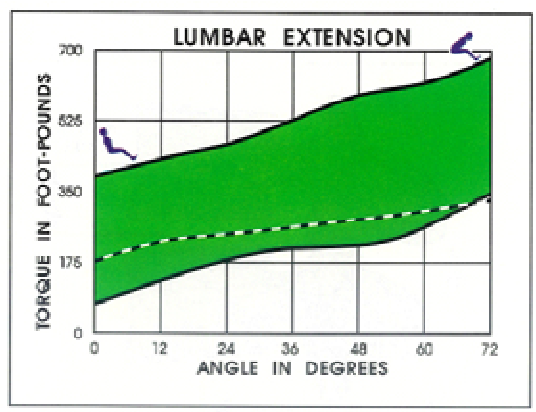


FIGURE 7-8 The lowest curve shows initial strength, the highest curve is strength after five months of specific exercise, and the dotted curve shows average strength for untrained male subjects. To the best of our knowledge at that time, those gains in strength were impossible, in any length of time; no other muscle in the body shows anything even approaching this potential for strength increases. No normal muscle ... but an atrophied muscle can produce such gains.

But even the increases in strength shown above turned out to be an understatement, his true gains in muscular strength were even higher; we were then unaware of the effects of stored-energy torque, assumed that changes in functional strength were in proportion to changes in muscular strength, which they are not. Later, when we became aware of and measured the results of stored-energy torque, it turned out that his true increases were 196 percent in the flexed position and 440 percent in full extension. Much higher in the flexed position than initially believed, and slightly lower in full extension. At that level of strength he was producing fifty percent more torque from the small muscles of the lumbar spine than he was from the much larger muscles of the thighs. A relationship that caused us initial surprise.

But the leverage provided by the joint system must also be considered. The knee joints have a gross mechanical disadvantage; if the quadriceps muscles produce a force of 100 pounds, the measured output of torque will be about seven foot-pounds. Which is why the quadriceps muscles are so large; they must be large in order to compensate for very poor leverage in the knee joints. But in the joints of the lumbar spine, in the flexed position, the muscles are provided with a mechanical advantage of at least two to one; if the muscles produce 100 pounds of force, the measured output will be at least 200 foot-pounds of torque.

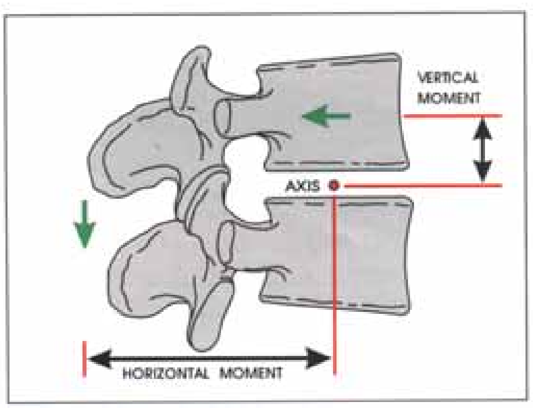


FIGURE 7-9 This drawing illustrates the mechanical advantage provided in the flexed position of the lumbar spine; the input of force from the muscles will be increased by the leverage of the joint system.

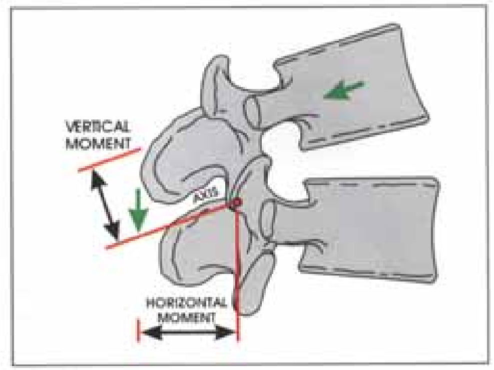


FIGURE 7-10 The mechanical advantage in the flexed position is reduced in a position of full extension of the lumbar spine; changes as a result of a relocation of the axis of rotation. In the flexed position, the axis of rotation is located between the vertebral bodies; but in full extension, the axis has changed to a position well to the rear of the posterior face of the lumbar vertebrae; in full extension, the axis is located in the facets. Relocation of the axis that reduces the mechanical advantage found in the

Previously-untrained subjects are usually much weaker in full extension than they are in the flexed position, and the loss of leverage as you move from the flexed position to full extension might appear to be responsible for the lower level of strength in the extended position. But trained subjects, after their initial level of strength has been greatly increased by specific exercise, usually produce the same level of true muscular strength, NMT, in every position throughout a full range of movement.

If the input of force from the muscles was constant in every position, then the output of measured torque would drop in direct proportion to any loss in leverage, but this does not happen. Which means that the force from the muscles is increasing as you move from the flexed position to full extension. Greater force from the muscles compensating for a loss in leverage. Which also means that some of the muscles that extend the lumbar spine are not involved throughout the full range of movement; become involved only as you move close to the fully-extended position. Apparently these muscles cannot be used in other positions; which helps to explain why they are usually so weak when a previously-untrained individual is first tested; never having been exposed to meaningful exercise, they remain in a state of atrophied weakness.

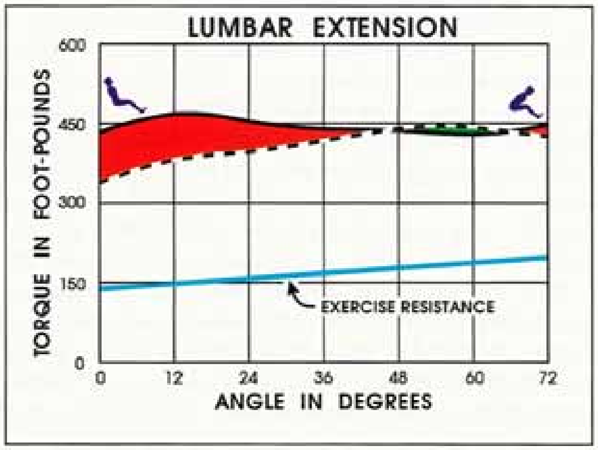


FIGURE 7-11 A test of fresh strength compared to a test of exhausted strength. On the left side of the chart there is a meaningful difference in the strength levels, fatigue from the exercise; but on the right side of the chart there was no change in strength, no fatigue from the exercise. Fatigue in his strongest position, but no fatigue in his weakest position; and this occurred even though the machine provided variable resistance, heavier resistance in his weakest position, and lighter resistance in his strongest position. Harder work caused no fatigue, while easier work did produce fatigue.

The above tests were produced during this subject's second test/exercise procedure; he was tested for fresh strength, was then exercised with what we considered an appropriate level of resistance, and was then retested for remaining strength immediately after the exercise. During his first procedure, approximately two weeks earlier, he failed during the exercise after fifteen repetitions with 175 foot-pounds of resistance, and since his fresh strength had increased by the time of this second test, we increased the resistance to 200 foot-pounds. But that was not enough of an increase; he should have been given heavier resistance.

The too-light level of resistance became obvious when he performed twenty-five repetitions with no sign of fatigue; so we stopped him at that point and immediately conducted the post-exercise test of strength. Fatigue from light resistance in his strongest position, but no fatigue from heavier resistance in his weakest position. It appeared that he had slow-twitch muscle fibers in part of the full-range movement, and a mixture of muscular fiber types in another part of the movement range. Which was a true indication of the actual situation; in the first half of a full-range movement, his fast-twitch fibers were atrophied; but in the last half of the movement, his fast-twitch fibers had been reactivated by heavy work in that limited part of the movement range. The level of resistance used in the exercise is shown by the blue line; higher resistance in the flexed position and lower resistance in the extended position; automatic variation in resistance provided by the cam.

Many years of water-ski activity had exposed his spinal muscles to a heavy workload near the extended part of the range, and had increased his strength to a level far above average in those positions; while doing nothing to increase his strength above avenge for an untrained man in the flexed position, which is usually the position of highest strength.

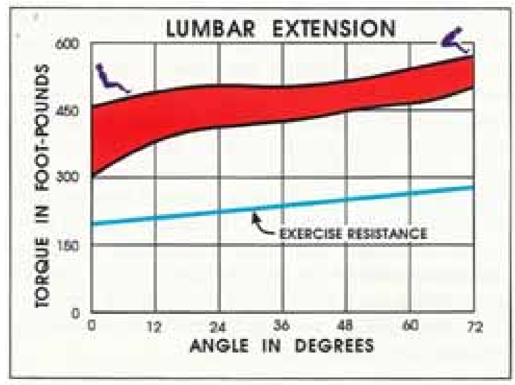


FIGURE 7-12 In a period of ten weeks following his first test, as a result of only five previous sessions, he increased his strength in the flexed position, his initially-weakest position, by 60 percent, with an increase in full extension of 33 percent, and with an increase about twenty degrees forward from full extension, his initially-strongest position, of 22 percent. His dynamic strength increased by 60 percent, from 15 repetitions with 175 to 15 with 280 foot-pounds of resistance.

But following this last test his fiber type appeared to have changed in the first half of a full-range movement; at a much higher level of strength near flexion, he started to show fatigue in that area. But these changes did not indicate an actual change in fiber type; instead, demonstrated the selective nature of atrophy. Fast-twitch fibers atrophy faster and to a greater extent than slow-twitch fibers. When first tested, his fast-twitch fibers in the first part of the movement range were nonfunctional from atrophy; but as strength was increased, these fibers started to function again.

A response that clearly supports a point mentioned earlier; some of the muscles that extend the lumbar spine are involved only in a position near full extension.

STRUCTURAL INTEGRITY OF THE SPINE

While the upper part of the spine, from T 10 through T 1, is provided firm support by the closed ribcage, the lower spine is supported primarily by the muscles, the tendons and the ligaments in that area; and weakness in any of these support structures can lead to injury. The need for soft-tissue strength in that part of the spine is beyond question.

Function is a term with a double meaning; function implies producing something, but it also means preventing something. The spine is designed to permit certain types of movement, but is also required to prevent other types of movement. But the spine itself is incapable of producing force in any direction, and has only a limited ability to resist force from any direction. In some ways the spine is similar to a tall, thin tower that has very limited ability to withstand horizontal forces, yet is required to resist high levels of force from the wind; resistance against horizontal force from the wind is provided by cables attached to the tower and anchored in the ground. Such cables provide no resistance against compression forces, but do prevent the tower from bending because they resist pulling forces.

The muscles, the tendons and the ligaments support the spine in a similar way; but unlike the cables supporting a tower, the spinal support-structures resist both pulling and compression forces. The bones and discs of the spine are primarily intended to resist compression forces, provide very little in the way of resistance against forces from any other direction.

The functions of the spine cannot be understood if the parts are viewed individually, become meaningful only when the functions of all of the parts are considered. Muscles, tendons and ligaments, collectively the soft tissues, on the left side of the spine resist stretching forces, and thus limit bending of the spine towards the right; bending towards the left is limited by the soft tissues on the right side of the spine. And the cross-sectional area of the soft tissues is large enough to provide meaningful resistance to compressional force. Without this support from the soft tissues, the spine could not remain in an upright position against the force produced by the weight of the torso. So the strength of these soft tissues is critical.

The spine is designed to permit bending, but is also intended to prevent bending beyond a degree that would become dangerous. In the early days of aviation, wings were very rigid structures, and were not very strong as a consequence. Modern airplane wings are designed to bend, and bending greatly increases their structural strength. To bend a wing up wards, you must stretch the wing's skin on the bottom surface while compressing the skin on the top of the wing; the greater the angle of bending, the higher the levels of compression and stretching forces. Which design permits bending up to a point, but stops additional bending; and the soft tissues support the spine in the same way. But like the wing, if exposed to a force that exceeds the coexisting level of structural strength, something will break.

Most of the bones are hollow for a good reason; because the center of a solid bar provides resistance primarily against compression forces, does very little in the way of resisting bending forces. Where weight is no consideration, you can use a solid bar or a pipe; but when weight must be considered, and when your primary concern is to resist bending forces, then the best choice is a pipe.

The horizontal distance from the center of the spine to the attachment points of the soft tissues is another critical consideration; the shorter this distance, the higher the level of required force. In the lower part of the spine, these distances are short; which means that a very high level of force is required to provide the support that the spine cannot provide for itself.

Structural integrity is primarily determined by cross-section; a two by four-inch timber is weaker than a four by four because the cross-section is smaller. Given the same chemical composition and the same density of material, structural strength normally changes in proportion to changes in cross-sectional area. Changes in shape also produce changes in structural strength, even when cross-sectional area remains constant; but this is not a significant factor when dealing with the structural strength of human body parts, because changes in cross-sectional area usually do not produce a change in the shape of the body parts.

Almost any design is a compromise, and the spine is no exception; but when all of the requirements are considered, the actual design of the spine and its supporting soft tissues would be difficult to improve, represents a masterpiece of structural engineering.

But having built it right, you still have to maintain it; and all of the tissues in the body are constantly changing, becoming stronger or becoming weaker. Future requirements are based upon recent demands; when you stop using something you send a signal to the body that it is no longer required; a lack of force in outer space leads to significant loss of bone mass; total immobilization of a joint produces both atrophy of the related muscles and tissue changes in the tendons and ligaments.

But when you use these tissues at a level that is close to the momentary limit of functional ability, this sends a clear signal to the body; tells the body that the existing level of function is not high enough to meet the requirements; and if improvement is possible, the body will provide it. Proper exercise provides this signal; does not produce following increases in strength, but stimulates them.

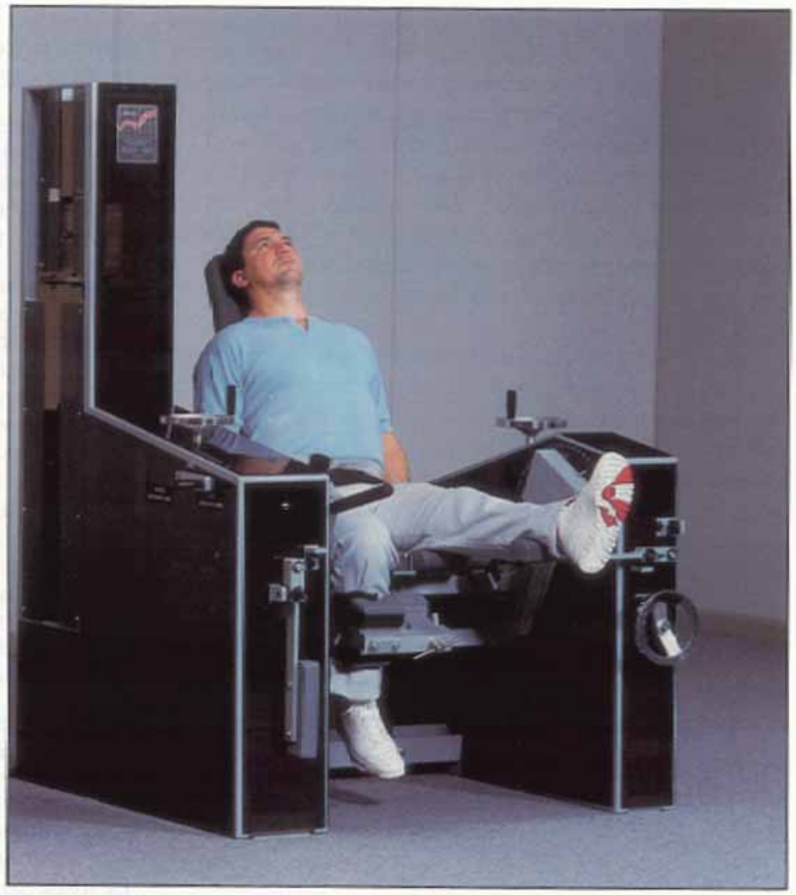
Proper exercise is important for every voluntary muscle in the body . . . but for the muscles of the lumbar spine it is critical.

RESEARCH: SPINAL STABILITY and INTERSEGMENTAL MUSCLE FORCES.

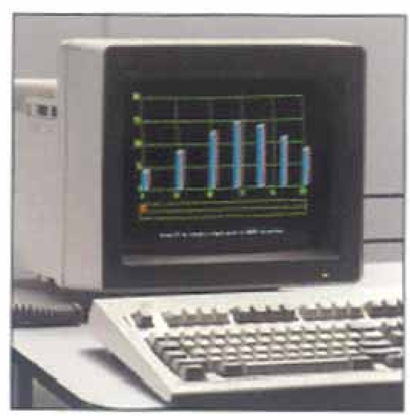
A Biomechanical Model, by Manohar Pahjabi, PhD, et al. Yale University School of Medicine and Hokkaido Medical School, Japan. Published in SPINE, volume 14, number 2, 1989.

"The human spinal column, devoid of musculature, is INCAPABLE of carrying the physiological loads imposed on it. It has been shown experimentally that an isolated fresh cadaveric spinal column from T 1 to the sacrum placed in an upright neutral position with sacrum fixed to the test table can carry a load of not more than 20 N before it buckles and becomes unstable. Therefore, muscles are necessary to stabilize the spine so that it can carry out its normal physiologic functions. This stabilizing function is in addition to the usual muscle function of producing motions of normal physiologic functions. This stabilizing function is in addition to the usual muscle function of producing motions of the body parts.

"Muscles play an important role in the etiology presentation, and treatment of low back disorders . . . Muscle strengthening exercises for the treatment of low-back pain are generally advocated. Furthermore, it has been shown that subjects are less likely to have low-back disorders. Therefore, it appears that adequate muscular function is required to stabilize the spine within its normal physiologic motions."



MedX Knee machines provide specific testing for both quadriceps and hamstring muscles, and specific exercise for the quadriceps. Testing and exercise procedures can be conducted with both legs working together or with either leg working alone. Range of movement for both testing and exercise can be limited on either or both ends of a full-range movement. Support is provided for an injured leg enclosed in a cast so that the other leg can be tested or exercised. Both functional strength and Net Muscular Torque are measured by the machine and recorded by the computer and the levels of strength are correlated and stored energy are measured by the machine and factored into test results in order to provide a measurement of true muscular strength.



CHAPTER 8
TESTING KNEE FUNCTION

FIGURE 8-1 Initial research to develop accurate testing tools for the muscles of the knee was started in January of 1972, more than twenty-one years ago, but we were not satisfied with this equipment until 1991; features and functions of this machine were first submitted to the FDA in April of 1991. But research was conducted at the Military Academy, West Point, in 1975, nearly sixteen years earlier; followed by several years of research at the University of Florida College of Medicine, in Gainesville; in both cases using prototypes of our current equipment.

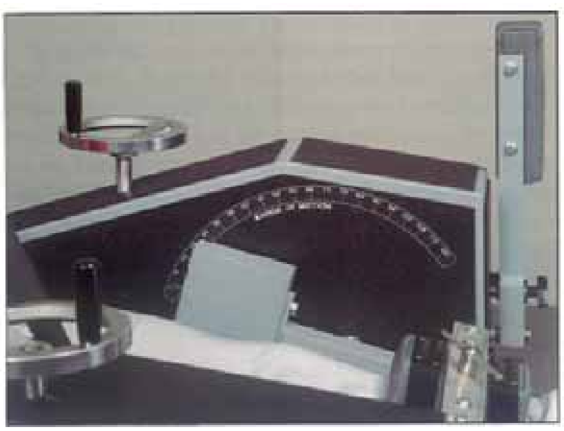


FIGURE 8-2 Range of movement (ROM) is displayed by a large goniometer (angle detector) and is recorded by the computer. ROM can be provided for a full range of movement or any desired part of a limited range.

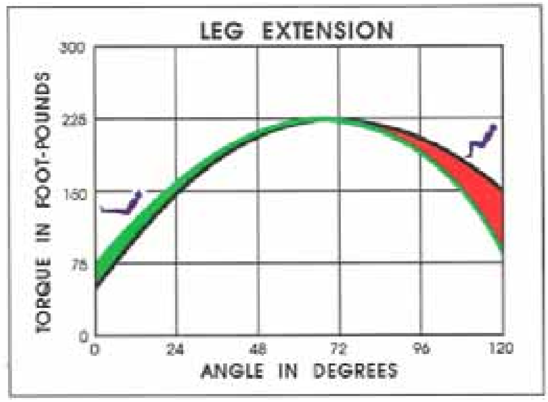


FIGURE 8-3 Curves of torque produced by a large male subject during a test of quadriceps large male subject during a test of quadriceps strength of one leg; comparing functional strength to the true level of strength, NMT. The colored areas between the curves show the degree of error introduced if the effects of nonmuscular torque are ignored. On the right side of the chart, in the position showing strength in the flexed position of the leg, nonmuscular factors (mass of the leg and stored energy) overstated true strength by 63 foot-pounds of torque; while the same factors produced an under statement of true strength near full extension of 22 foot-pounds.

More than 20 years ago, our prototypes of leg extension machines could measure torque, the only remaining problem then being our inability to prevent unwanted movement of the involved body parts; without which it was impossible to correlate measured torque with positional measurements. Seven distinct problems related to accurate correlation of strength with position have now been identified; collectively producing large magnitudes of error in positional measurements of the involved body parts.

Six of these problems were eventually removed or reduced to such low levels that any remaining Six of these problems were eventually removed or reduced to such low levels that any remaining degree of error was insignificant; but it then required several more years of work to solve the final problem; unwanted rise of the pelvis under load, which changed the relative positions of the involved body parts in a manner that could not be measured.

This correlation is essential because changes in relative positions of the body parts produce changes in strength; an apparent gain in strength may actually represent a change to a stronger position, rather than a true increase in strength. Such considerations being critical during tests of quadriceps strength, where the level of strength normally rises as movement occurs and then drops as movement continues. A somewhat bell-shaped strength curve.

In contrast, the strength curve produced in all other MedX machines is a straight line, descending from the highest level in the starting position to the lowest level in the finishing position. A coincidental circumstance that produced a valuable result. Since strength testing is usually conducted with attempted movement in the direction of a weaker range of movement, and given a straight-line, descending curve, any error in positional measurement leads to understatement of results rather than overstatement.

If, for example, a subject was tested in a position of 100 degrees, with a result of 100 foot-pounds of torque, if later retested in the same position, then showing a strength of 200 foot-pounds, this would indicate an increase of 100 percent, from 100 to 200. But the actual gain would be somewhat higher; because, at the higher level of strength in the second test, any unwanted movement would be produced in the direction of a weaker position; so, during the second test, the actual position, under the higher load, might be 99 degrees rather than the selected position of 100 degrees. Meaning that torque had been increased 100 percent, even though the second test was conducted in a slightly weaker position; thus meaning that the true increase in strength was some what more than the indicated gain of 100 percent. But with a bell-shaped strength curve like the one

produced in leg-extension testing, this means that errors in both directions can be introduced by such unwanted changes in position.

But for many years prior to the completion of our knee machine, we conducted research with thousands of subjects; and discovered several important but previously unsuspected factors that are critical for rehabilitation. We discovered, among other things, the only meaningful protocol for determining fatigue characteristics, the Type S, specific, response to limited-range work and the Type G, general, response to limited-range work.

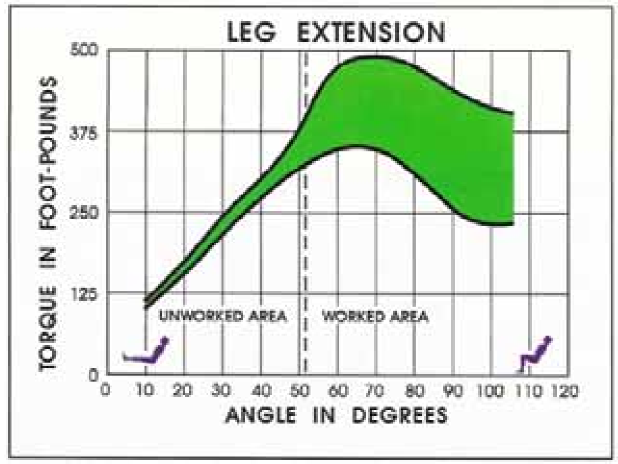


FIGURE 8-4 A Type S, selective, response to exercise. Provided largely, but not entirely, with limited-range exercise, work primarily in the first half of full-range movement, this subject increased his quadriceps strength to an enormous degree in the worked range of movement; as a result of only seventeen exercises during a period of more than eighteen weeks, less than one exercise each week. In the range of movement that we called the unworked area, his gains in strength were much lower, an av erage of only 13 percent in the unworked area, com pared to an average of more than 60 percent in the worked area, with gains of more than 80 percent in some positions within the worked area.

But some work was performed in the unworked area during that period; of the total of seventeen exercise sessions, one involved work only in the positions we are calling unworked, one was only in the midrange of possible movement, and one involved a full range of movement, and, additionally, repeated static testing was performed throughout a full range of movement, which provided some exercise in the unworked area. Nevertheless, the results were largely limited to the worked area, a very distinct Type S response to limited range exercise, gains in the worked area with little or no gains in the unworked area.

Following the result, shown above, several weeks of continued exercise performed once each week failed to produce any additional gain in strength; whereupon, we started exercising him twice each week to see if more frequent exercise was required. But several months of twice weekly exercise produced no change in strength. Having discovered that more frequent exercise was not the solution, we then changed to limited-range exercise only in the last half of the full-range of movement, avoided any exercise in the previously worked area. Five weeks of exercise in the previously unworked range produced the following results.

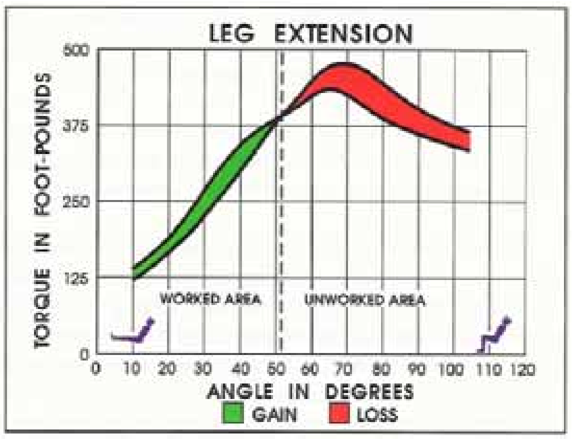


FIGURE 8-5 Exercised once each week for five weeks in the previously unworked, last half of a full-range movement, he immediately started to increase his strength in the last half of the movement range, while losing strength in the first half of the range; gains in one part of the movement range with simultaneous losses of strength in another part of the range. The red area shows losses in strength, while the green area shows gains.

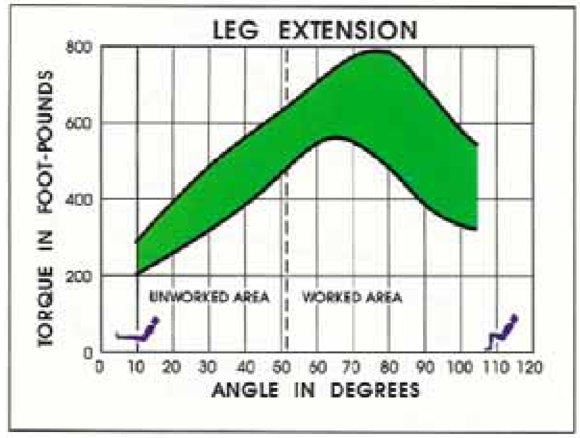


FIGURE 8-6 In contrast with Type S results shown by Figures 8-4 and 8-5, this chart shows strength increases produced by a Type G, general, subject as a result of only 21 limited-range exercise sessions during a period of 13 weeks. While his strength gains were better in the worked area, he produced very significant, if not proportionate, gains even in the unworked range of movement. This subject was exercised only in the area called worked, and was tested for full-range static strength only three times during that period.

Another important point related to this subject's results was the magnitude of gains produced in a relatively short period by infrequent exercise. For fifteen years immediately prior to this research, this subject had been performing heavy, full-range exercise for these muscles three times weekly, with three sets of the exercise during each session, a total of nine weekly exercises; with nothing in the way of additional strength gains during the last several years of such training. A fatigue-characteristics test of his quadriceps muscles indicated a very high percentage of fast-twitch fibers; and given this fiber type he could not produce additional strength increases when exercised frequently, had remained in a state of continuous overtraining for several years. An unavoidable conclusion clearly established by the increases in strength that were produced when his exercise was reduced to a small percentage of his earlier exercise program.

His dynamic strength gains were in direct proportion to increases in static strength; and at the end of the thirteen-week program he was the strongest man we have ever tested for the strength of the quadriceps muscles, producing more than 791 foot-pounds of torque in his strongest position with fresh muscles. The strongest among many thousands of subjects, some of whom were far above average strength.

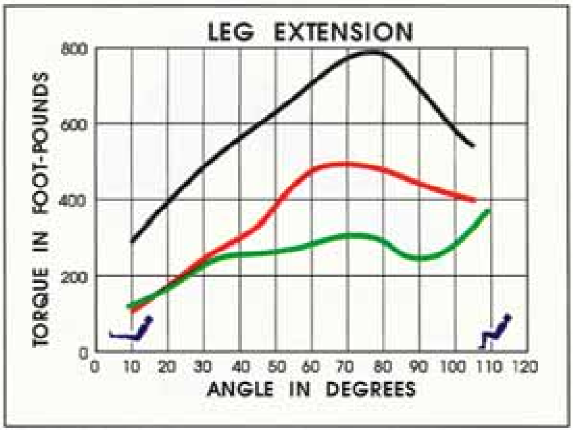


FIGURE 8-7 A comparison of quadriceps strength of three subjects; the highest curve was the fresh strength of the Type G, fast-twitch subject mentioned above . . the middle curve was the fresh strength of the Type S subject mentioned earlier, a man with a random mixture of fibers in his quadriceps muscles ... while the lowest curve shows fresh strength of a world-class power lifter, a man who set a record in the squat lift only a few weeks after this test.

He was stunned by the results, and demanded to be retested the following day; but if twenty years of continuous training had not produced a high level of quadriceps strength, then twenty-four hours would not change it; when retested the next day his results were almost identical. He was weak as a result of a very high percentage of slow-twitch fibers in the quadriceps muscles, showed a high level of endurance during the exercise part of the testing procedure, but a very low level of strength for a man of his size.

Then how could he squat with more than 1,000 pounds of weight? Because squatting strength is largely a result of the strength of the hip muscles, the hamstring muscles, and the lower-back muscles. He would not permit us to test the strength of his muscles in other parts of the body; but even without these tests it is obvious that he had a different fiber-type in the other muscles; given slow-twitch fibers in all of his muscles, he would not be setting records in the squat.

TESTING

Strength testing in the MedX knee machine can be conducted with both legs simultaneously, or with either leg working alone, which provides the important ability to compare one leg with the other leg. An apparently normal leg may prove to be abnormal when compared to the other leg; and, during rehabilitation of an injured leg, testing of the normal leg provides a target of possible strength for the injured leg.

The machine also provides the capability of testing or exercising a normal leg while the other leg is in a cast, and provides support for a leg in a cast. Range of movement for both testing and exercise is 120 degrees of movement, but range can be limited on either or both ends of a full-range movement if desired.

241 levels of resistance for exercise are provided; from a minimum of 20 foot-pounds to a maximum of 500 foot-pounds, in increments of 2 foot-pounds.

Testing can be conducted in any or all of twenty-one positions, in increments of 6 degrees; but with a normal, full-range movement of 120 degrees, testing is usually conducted in each of eleven positions, in increments of 12 degrees; or, if desired, in six positions with increments of 24 degrees. Nonmuscular torque is measured by the machine and factored into the test results by the computer, providing a true test of strength, NMT.

Position of the back pad is adjustable to compensate for variation in femur length on an individual basis; and the relative angle of the back pad to the seat is designed to remove tension in the hamstring muscles that would inhibit function of the quadriceps muscles if the subject was seated in an upright position relative to the seat. If a subject leans forward during leg-extension testing or exercise, the movement towards torso flexion stretches the hamstring muscles over the hip joint, while extension of the leg produces stretching of the hamstring muscles over the knee joint; the hamstring muscles are stretched on both ends, and the resulting tension in these muscles inhibits function of the quadriceps muscles near a position of full extension.

Even sitting upright, with a relative angle of 90 degrees between the seat and the back pad, will inhibit quadriceps function from hamstring tension with most subjects. Tests conducted in that posture are biased on the low side near a position of full extension. But the solution to this problem is simple; the torso should remain at a relative angle of about 120 degrees to the surface of the seat; which position removes the unwanted tension in the hamstring muscles.

EFFECTS and RESULTS

As used earlier, the term RESULT means a long-term change in strength produced (or stimulated) by exercise; whereas, the term EFFECT means the immediate change produced by exercise. Effects and results are both consequences, indicate changes in strength; but an effect is an immediate consequence, while a result is a consequence that occurs days or weeks later. Fatigue from exercise is an effect, an immediate consequence; while a gain in strength from one test to a later test is a result, a long-term consequence. This being a distinction in terms that is important in relation to the following example.

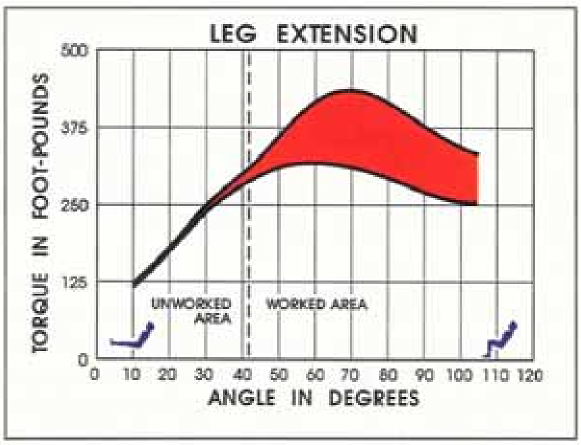


FIGURE 8-8 This is an effects test with a Type S (specific) subject, an individual that shows limited-range response to limited-range exercise. Tested for full-range strength of the quadriceps muscles, the highest curve shown on this chart, then worked to a point of failure with exercise limited to the area shown on the right side of the chart, from the flexed position of the leg to the midrange of possible movement; when retested following the exercise, strength was reduced within the worked range from fatigue, with no change in strength in the unworked range, showing no fatigue in the last part of a full range of movement. A Type S response to limited-range exercise.

Such specific effects from limited-range work can the subject did all of the negative work. be produced on either end of the movement range, or within the midrange of possible movement; fatigue will be shown only in the worked area. In contrast, a Type G (general) subject will show fatigue throughout the full range of movement as an effect of limited-range exercise.

Since many of the exercises in widespread use actually provide limited-range resistance, Type S subjects will show little or nothing in the way of strength gains from these exercises in some positions; examples for the legs are leg-presses and squats, both of which may appear to provide full-range exercise, because they involve full-range movement around the knee axis; but neither of which actually provide meaningful resistance near a position of full extension of the leg, and no resistance in a position of full extension. The solution being the use of the leg extension exercise; which does provide resistance for proper exercise throughout a full range of movement.

NEGATIVE-ACCENTUATED EXERCISE

Proper exercise stimulates increases in both muscular size and strength; but we still do not know exactly why this happens, or how it occurs. But it appears that two factors are involved: the level of fatigue produced by the exercise, and the time required to produce that level of fatigue. Within reasonable limits, a higher level of fatigue is better, but only if it can be produced within a short period of time.

In 1972, then having no opinion regarding the relative merits of positive and negative work during exercise, we conducted a research program to determine the results of negative-only exercise, a style of exercise that involved no positive work of any kind. Using barbells and Nautilus machines, the lifting part of the exercise was performed by several assistants; so that the subject being worked could then perform only the lowering part of the exercise, the negative part of the work. For example, in a bench-press exercise with a barbell, two helpers lifted the barbell into position above the subject's chest, with no help from the subject; and when the helpers released the barbell in the top position, the subject slowly lowered it until reaching the lowest position, with the barbell then touching his chest. Whereupon, the helpers lifted it again, and the subject lowered it again, and so on; the helpers doing all of the positive work while

NOTE: With a few exceptions, this is usually not a practical form of exercise, since it requires help; and it is unavoidably a dangerous style of exercise, since the assistants may release the weight before the subject is expecting them to . . in which case the weight will fall and the subject may be injured.

But we were very careful and no injuries were produced; and our interest was limited to the value of pure negative work.

Each exercise was stopped when the subject started to lose control of the weight ... when the speed of downwards movement started to increase, and when the subject could not prevent this increase in speed. When eight or more repetitions could be performed while still controlling the speed of downwards movement, the resistance was increased. And we quickly learned that only one set of each exercise was required, and only two weekly training sessions; more than one set of each exercise, or more than two weekly workouts, produced so much fatigue that the subjects could not fully recover between workouts.

The subjects in this study included high-school football players, two professional football players, and several advanced bodybuilders; all subjects being far above an average level of strength at the start of the program. Continued for a period of three months, this style of training produced better results than any form of exercise we had tried previously.

We did not then understand why the results were so outstanding; but we do now. Because of the increase in muscular friction that comes with fatigue, friction that increases negative strength while reducing positive strength, we were producing levels of fatigue that would be impossible to reach while performing any usual style of exercise. Impossible to reach within a reasonable length of time.

If your fresh level of strength is 100, and if you exercise with resistance of 80, then you will be forced to stop when your remaining strength drops below 80; your fresh strength will be reduced by about 21 percent. But if you immediately continued the exercise with resistance of 60, then you would fail when remaining strength was about 59, and if you then reduced the resistance to 40 in order to continue, you would fail when remaining strength was only 39. If stopped at that point, you would have produced a high level of fatigue, but doing so would require approximately thirty repetitions of the exercise. The level of resulting fatigue would be good for the purpose of stimulating strength increases; but the amount of work required to produce that level of fatigue would not be good for the same purpose.

With the negative-only exercises outlined above, we were reducing the level of fresh strength by at least 80 percent, and were reaching that high level of fatigue within a relatively brief period of time. But this still left us with the unavoidable problems associated with a negative-only style of exercise; regardless of potential value, an exercise must be both practical and safe.

Problems that were eventually solved in the following manner: Negative-accentuated exercise provides the benefits of negative-only exercise, but without the problems.

Negative-accentuated exercise cannot be performed with a barbell, and cannot be performed during some exercises using weight machines, so it does not solve the problems in all cases; but it can be used in any exercise that involves both limbs working together. In a leg-press exercise, for example, the weight would be lifted by both legs, but would then be lowered by only one leg; both legs would share the positive part of the exercise, but only one leg would perform the negative part. Up with both legs, down with the right leg only, up with both legs again, down with the left leg only, and so on.

If your fresh strength using both legs was 100, you would normally exercise with resistance of 80, and would fail when you could no longer lift the weight with both legs; would fail with a remaining strength of about 79. But with a negative-accentuated style of training you would use a lower level of resistance; instead of 80 percent of fresh strength you would use only 50 percent. With a usual exercise, using resistance of 80, each leg would lift, and lower, 40, but with negative-accentuated exercise, using resistance of 50, each leg would lift only 25, but would lower 50. Resistance would be lower during the positive work, but higher during the negative work

Performed properly, at a slow speed, you will fail during the positive part of the exercise; will fail when both legs can no longer lift the weight. Having reduced your fresh positive strength by more than 50 percent; a level of fatigue far higher then the 21 percent loss of fresh strength produced in most exercises. But having failed to lift the weight with both legs, if somebody will lift it for you, then you can still lower the weight under full control with only one leg. Before the exercise your negative strength was 40 percent higher than your positive strength, but that ratio of negative to positive strength changes as a result of fatigue, changes because of an increase in muscular friction; friction that reduces positive strength while simultaneously increasing negative strength.

This negative-accentuated style of exercise can be used with the MedX knee machine, and may well provide the most productive form of exercise for the quadriceps muscles; but should not be performed more than twice each week with any subject, because of the high level of resulting fatigue.

Apart from the description above, the only additional information required for proper performance of this style of exercise is related to the position in the exercise where the weight is shifted from both legs to one leg; this hand-off of the weight to one leg should be performed smoothly and slowly. Lift the weight to the top position with both legs, and pause in that position, with both legs fully extended, then slowly move one leg away from the resistance pad, so that the weight is then being held in the fully-extended position by only one leg; if you cannot hold the weight with only one leg, then the resistance is too heavy.

Having carefully shifted the load to one leg, then slowly start to lower the weight using only one leg; the downwards speed of movement should be slow and steady; and if you cannot prevent an increase in the downwards speed of movement, then the resistance is too heavy. But with a proper level of resistance, together with the correct style of performance, failure will be produced when you can no longer lift the weight with both legs.

Negative-accentuated exercise is one of the safest styles of exercise, does not expose the subject to high levels of force from impact; but does produce the high level of fatigue required to stimulate increases in strength, and produces this level of

NOTE: Having observed the results we produced with a negative-only style of exercise during the research in 1972, coach Bill Bradford of the DeLand, Florida, high-school, then started a team . . . and trained his athletes with negative-only exercise. Starting competition in 1973, with no previous weightlifting experience, Bradford then established a record that is probably unprecedented In sports; his teams were untied and undefeated for a period of seven years of competition, won more than a hundred weightlifting competitions.

THE RATIO OF QUADRICEPS STRENGTH TO HAMSTRING STRENGTH

During the last twenty years, hundreds of published articles have mentioned the relationship of quadriceps strength to hamstring strength; and it has generally been accepted that this ratio is important for both functional ability and the prevention of injury. And it probably is important; but all earlier attempts to measure this ratio were misleading at best. Isokinetic tests performed in attempts to determine this ratio were biased to such a degree that they were meaningless. Biased by impact forces that are unavoidable in any dynamic testing procedure, by torque produced by the weight of the involved body parts, by friction and by torque produced by stored energy.

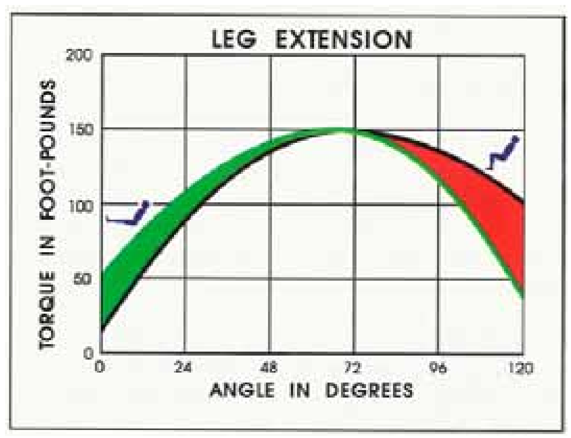


FIGURE 8-9 A comparison of tested functional strength to the true level of muscular strength, NMT, during leg extension (quadriceps). On the right side of this chart, showing strength in the flexed position of the leg, the true level of strength was overstated by 65 foot-pounds of nonmuscular torque (weight of the lower leg and stored energy). On the left side of this chart, showing strength near full extension of the leg, nonmuscular torque understated the true level of strength by 31 foot-pounds of torque. The curve of tested functional strength is black.

The green curve shows the true level of muscular strength, NMT. The tested level of functional strength in the flexed position was reduced from 102 to only 37 foot-pounds; a very significant difference. Near full extension of the leg, tested functional strength was increased from 17 foot-pounds of torque to a true level of 48; an increase of nearly 200 percent in that position.

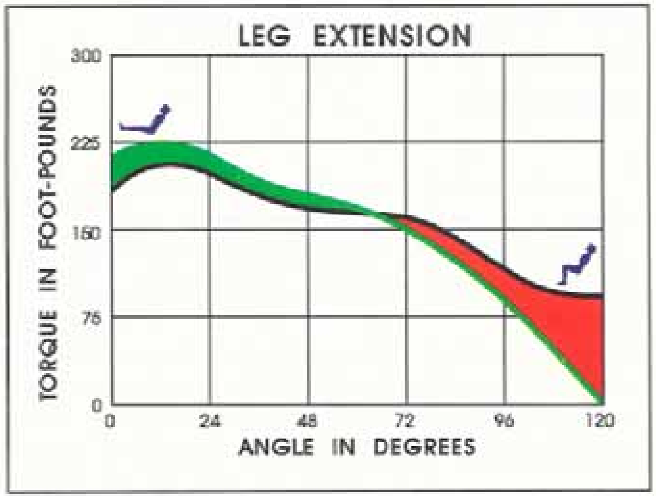


FIGURE 8-10 When testing strength of the hamstring muscles, nonmuscular torque produces bias in the opposite direction; overstates true strength when the leg is straight and understates true strength when the leg is flexed.

The green curve shows the tested level of functional strength of the hamstring muscles throughout a range of 120 degrees. The black curve shows the true level of strength; lower than indicated by the functional test when the leg was straight and higher when the leg was flexed. Again showing very significant differences between functional strength and true strength.

In the flexed position, functional strength was zero; while true strength was 89 foot-pounds of torque. In that position, nonmuscular torque and true muscular strength, NMT, were equal and opposite.

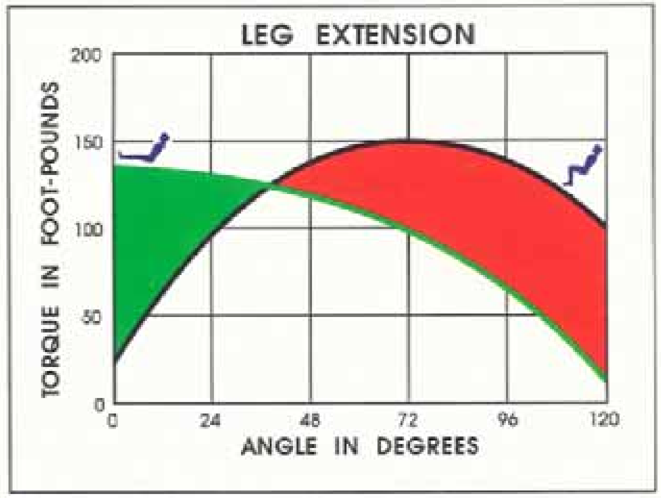


FIGURE 8-11 A comparison of functional strength of the quadriceps to functional strength of the hamstrings. If the ratio of strength is based upon a comparison of these two tests of functional strength, the results will be misleading. The true ratio is shown by the following example.

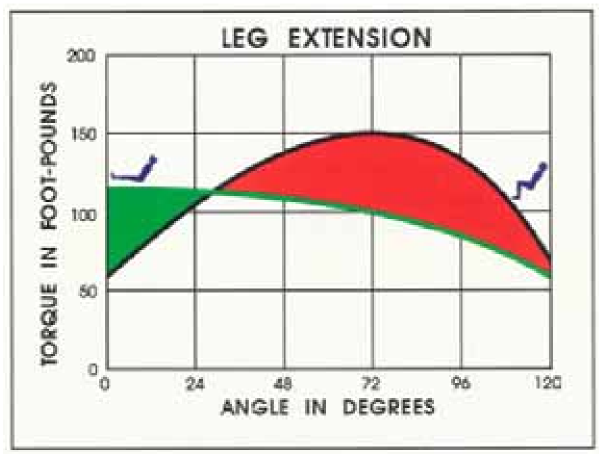


FIGURE 8-12 The true ratio of strength of the quadriceps muscles to strength of the hamstring muscles is shown by this chart; the curve of quadriceps strength is black, while the curve of hamstring strength is green. A comparison of this true ratio to the results shown by Figure 8-11 (functional test results) shows significant differences.

CHAPTER 9

Center for Exercise Science

School of Medicine,
University of Florida, Gainesville

MedX Research

PUBLISHED RESEARCH

1. "Effect of reduced training frequency on muscular strength" (International Journal of Sports Medicine,1988).
2. "Effect of visual feedback on repeated trials of full range-of-motion isometric strength" (Medicine and Science in Sports and Exercise, 1988).
3. "Comparison of two versus three days per week of variable resistance training during 10 and 18 week programs" (International Journal of Sports medicine, 1989).
4. "Specificity of limited range-of-motion variable resistance training" (Medicine and Science in Sports and Exercise, 1989).
5. "Effect of resistance training on lumbar extension strength" (American Journal of Sports Medicine, 1989).
6. "Quantitative assessment of full range-of-motion isometric lumbar extension strength" (Spine, 1990).
7. "Effect of training frequency and specificity on isometric lumbar extension strength" (Spine, 1990).
8. "Constant versus variable resistance knee extension training" (Medicine and Science in Sports and Exercise, 1990).
9. "Reliability and variability of isometric torso rotation strength measurement" (Medicine and Science in Sports and Exercise, 1990).
10. "Effect of order of multiple joint angle testing for the quantification of isometric lumbar extension strength" Medicine and Science in Sports and Exercise, 1990).
11. "Non-specificity of limited range-of-motion lumbar extension strength training" (Medicine and Science in Sports and Exercise, 1990).
12. "Effect of 12 and 20 weeks of resistance training on lumbar extension strength" (Physical Therapy, 1991).
13. "Injuries and adherence to aerobic and strength training exercise programs for the elderly" (Medicine and Science in Sports and Exercise, 1991).
14. "Accuracy of counterweighting to account for upper body mass in testing lumbar extension strength" (Medicine and Science in Sports and Exercise, 1991).
15. "Quantitative assessment of isometric lumbar extension net muscular torque" (Medicine and Science in Sports and Exercise, 1991).
16. "Effect of training frequency on cervical rotation strength" (Medicine and Science in Sports and Exercise,1991)
17. "Quantitative assessment of isometric torso rotation net muscular torque" (Archives of Physical Medicine and Rehabilitation, 1991).
18. Effect of testing order on isometric torso rotation strength" (International Journal of Sports Medicine, 1991).
19. "A physiological evaluation of elite professional water-skiers" (National Strength and Conditioning Association Journal)
20. “Quantitative assessment and training of isometric cervical extension strength “ (The American Journal of Sports Medicine, 1992).
21. "Comparison of two restraint systems for pelvic stabilization on isometric lumbar extension strength" (Journal of Orthopaedic and Sports Physical Therapy, 1992).

22. "Effect of reduced training frequency and detraining on lumbar extension strength" (Spine, 1992). 23.
23. "Quantitative assessment of isometric cervical rotation net muscular torque" (Medicine and Science in Sports and Exercise, 1992).
24. "Single versus multiple set dynamic and isometric lumbar extension strength" (Spine Rehabilitation, 1993).
25. "Lumbar strengthening in chronic low back pain patients: Psychological and physiological benefits" (Spine, 1993).
26. "Effect of training with pelvic stabilization on lumbar extension strength" (Archives of Physical Medicine and Rehabilitation)
27. "Effect of frequency and volume of resistance on cervical extension strength" (Archives of Physical Medicine and Rehabilitation).
28. "Angle specific isometric knee flexion /extension torque ratios" (Journal of Orthopaedic and Sports Physical Therapy, 1993).

UNPUBLISHED RESEARCH

1. "Effect of long-term resistance training on the development and maintenance of isometric lumbar extension strength"
2. "Effect of isolated lumbar extension resistance training on symptomatology and strengthening of patients with mild chronic low back pain."
3. "Effect of low-back training on lumbar extension strength in female collegiate tennis players"
4. "Effect of concurrent visual feedback and knowledge of previous results on isometric lumbar extension strength"
5. "Isometric lumbar extension strength in female collegiate tennis players: A comparison among athletic populations"
6. Adaptations in lumbar extensor muscle strength and cross-sectional area of the lumbar extensor muscles following resistance training"
7. "Effect of submaximal effort and knowledge of previous results on the reliability of lumbar extension strength"
8. "Effect of training frequency on the development of isometric torso rotation strength (one and two days per week)"
9. "Effect of training frequency on torso rotation strength (one, two, and three days per week)"
10. "Quantitative assessment of full range-of-motion cervical rotation strength"
11. "Quantitative assessment of full range-of-motion isometric knee flexion and extension strength"
12. "The reliability of repeated isometric strength measurements at different joint angles"
13. "Isometric evaluation of dynamic muscular strength: Acute changes and training responses"
14. "Isometric lumbar extension strength of male collegiate swimmers"
15. "Isometric lumbar muscle strength in 60-92 year old male track athletes"
16. 'The effect of training volume on the development of isometric knee flexion and extension torque'
17. "The evaluation and rehabilitation of the lumbar extensor muscles in patients with moderate low back pain and work-related injuries.