The Future of Exercise

(1997 and Beyond)

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Rehabilitation

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

Hippocrates

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.

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 point 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 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 force.

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.

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 overtrainig with some subjects.

Contrary to somewhat common misconceptions, the force involved in the negative part of the exercise is actually lower that 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 gains 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 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 s 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 1RM 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 whatever 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 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 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 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 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 n 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.

fig. 1

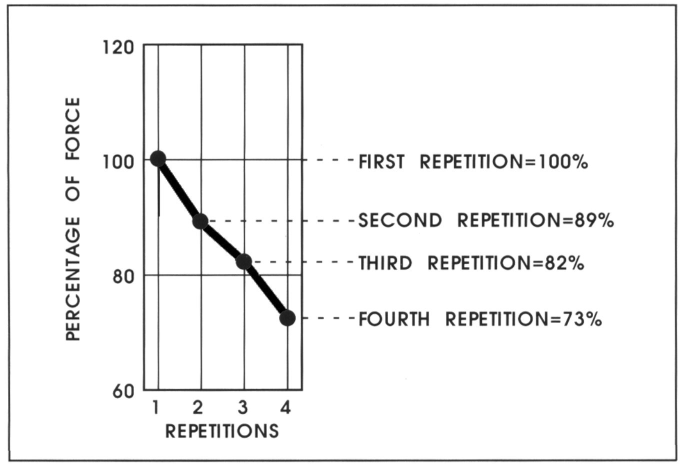


fig. 2

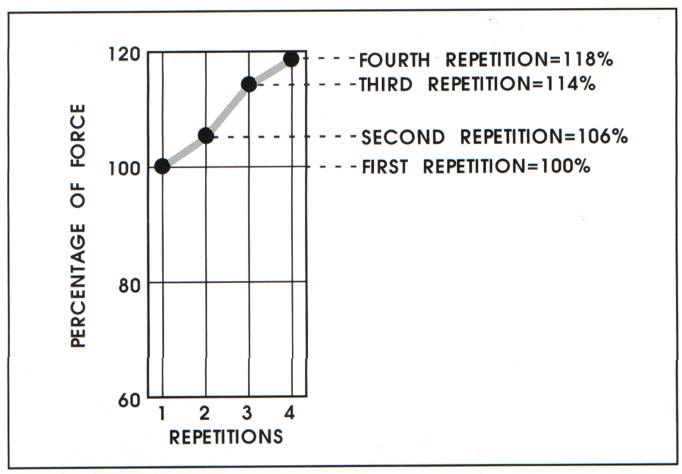
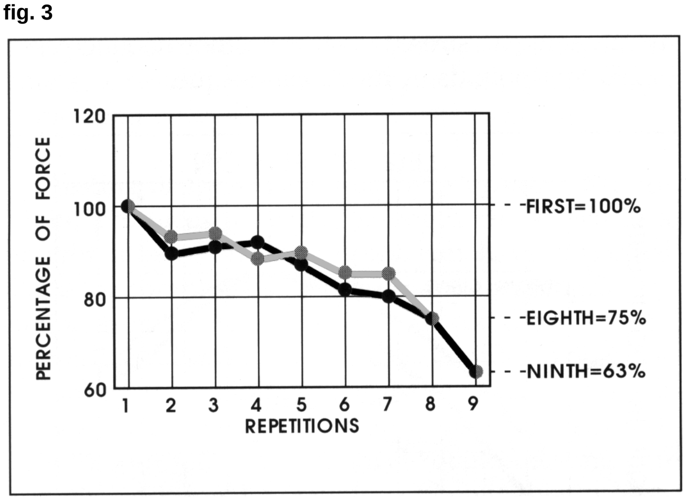


fig. 3



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. But when an initial limited range of movement is produced by muscular weakness, the range of movement will be increased as strength is increasing 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 nonmascular 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.

fig. 4

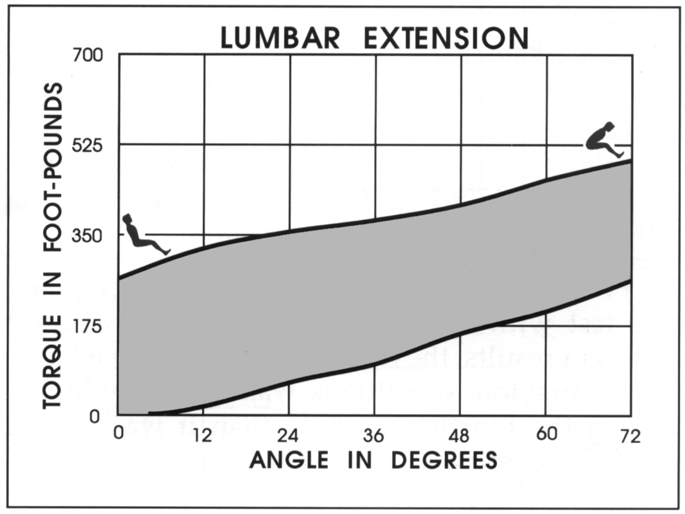


Figure 4: When first tested, this subject could not produce any measurable torque in a position of full extension. In that position, his existing level of muscular torque was equal to stored-energy torque acting in the opposite direction; so functional strength was zero. Six degrees forward from full extension, he could produce only 4 foot-pounds of functional torque. Five months later, his strength in that position had increased to 296 foot-pounds of functional torque.

fig. 5

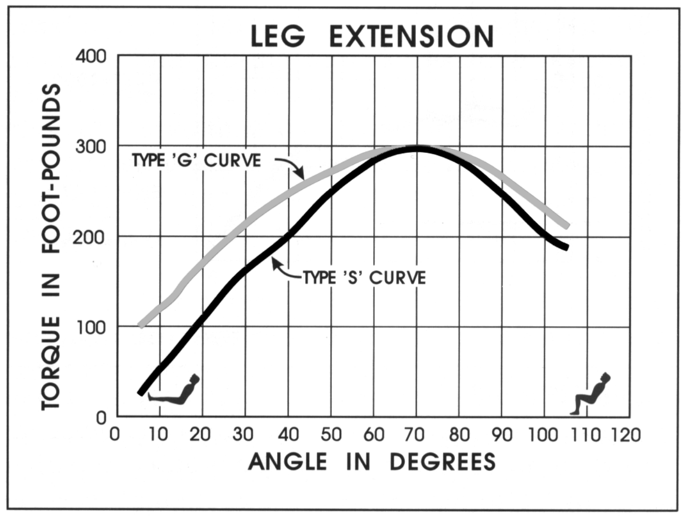


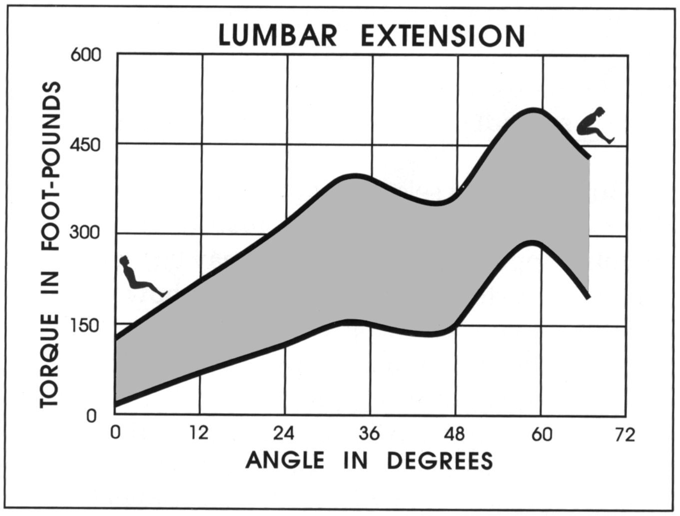
Figure 5: The strength curve produced by quadriceps testing is usually relatively low in the flexed position, highest as you near the midrange of movement, and lowest near full extension of the leg, a bell-shaped curve; but there is a wide range of possible shapes even with normal subjects; differences 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 unworked 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 unworked 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 shape of the strength curves when properly-trained individuals are compared, but there will 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 fig. 6



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 6: Fresh and exhausted levels of strength showing the same abnormal shape are clear proof of abnormality. A high level of fatigue produced by brief and relatively light exercise indicates a high percentage of fast-twitch fibers in the lumbar muscles. The grey 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-type 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 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-extension 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 strength in dull extension by 31 percent. The additional weeks of training changed the shape of their strength curve, produced much flatter curves.

fig. 7

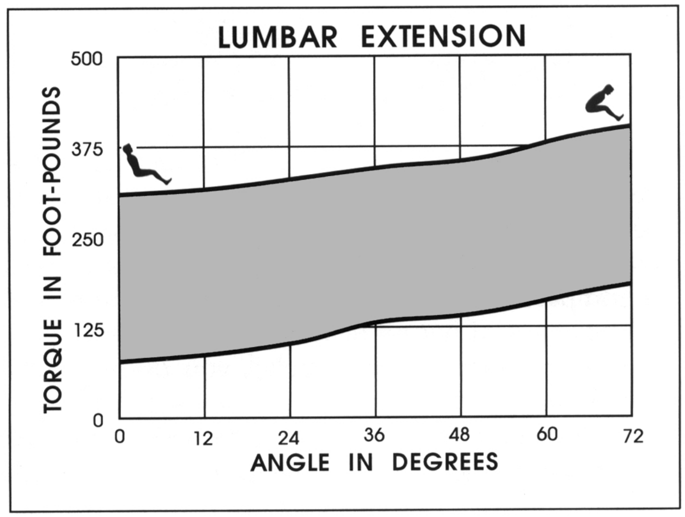


Figure 7: Peak level of functional strength following several months of isolated exercise; exercise that increased strength in the flexed position by 117 percent and strength in full extension by 300 percent. The grey area shows increases in functional strength.

fig. 8

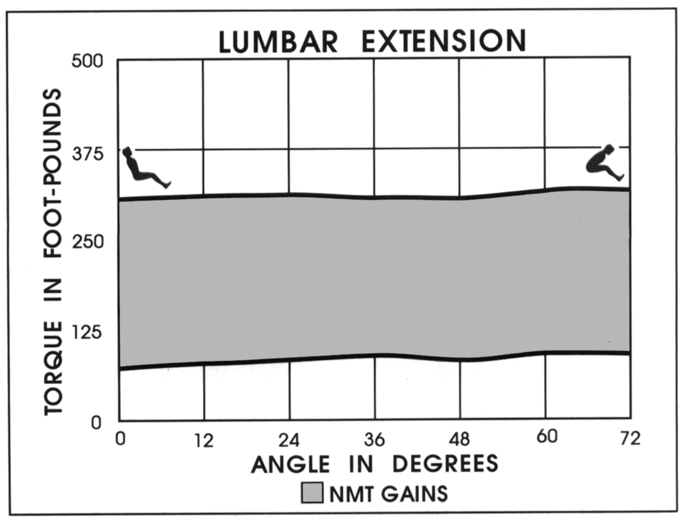


Figure 8: Corrected for the errors produced by nonmuscluar torque, these curves show true levels of strength of the same subject, Figure 64. The grey area showing changes in true strength, NMT. True strength in the flexed position increased by 251 percent, compared to the change of 117 percent in functional 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 this final level of true strength, this subject produced an almost perfectly-flat curve of torque; throughout the range, his average true strength 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.