# The Future of Exercise
## (1997 and Beyond)

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# 11

# 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.

fig. 1

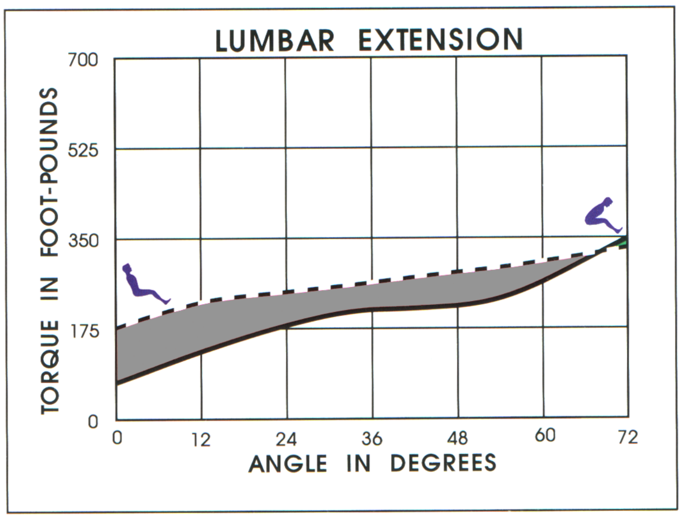
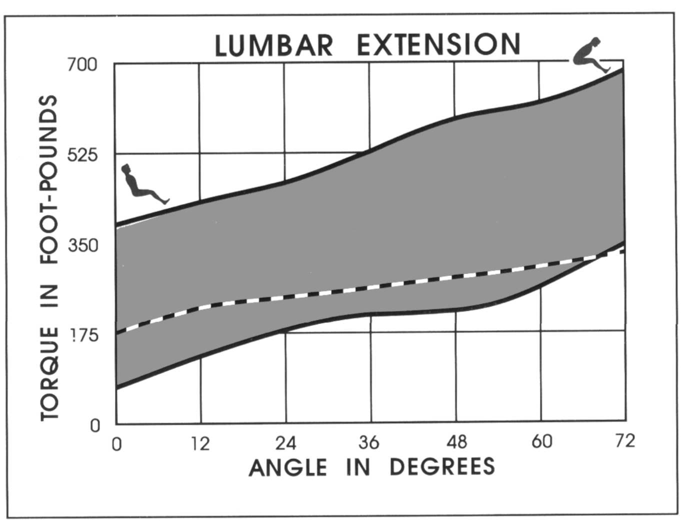



fig. 2




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 1: Initial strength of the subject mentioned above, compared to average strength for an untrained subject. The gray area between the two curves shows strength below average.

Figure 2: 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.

fig. 3

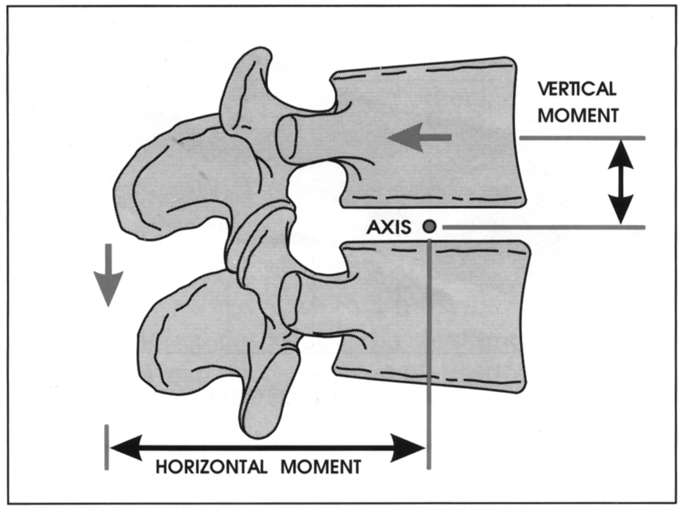



fig. 4

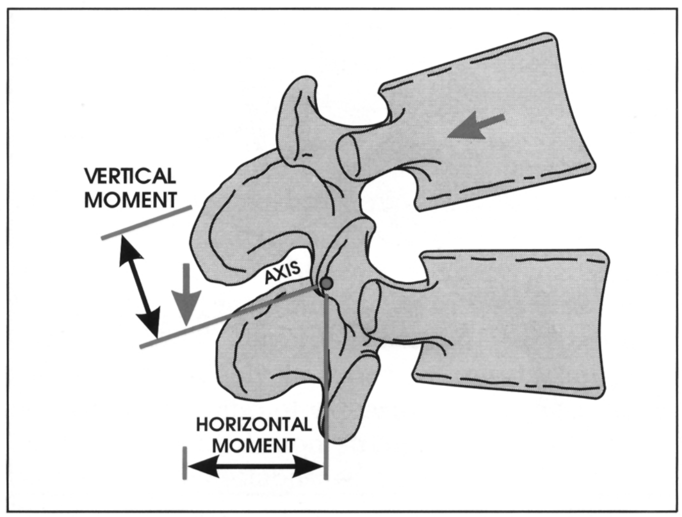



Figure 3: This drawing illustrates the mechanical advantage provided in the flexed position of the lumbar spine; the input of force from the muscles will be increased by the leverage of the joint system.

Figure 4: The mechanical advantage in the flexed position is reduced in a position of full extension of the lumbar spine; changes as a result of 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 flexed position.

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.

fig. 5

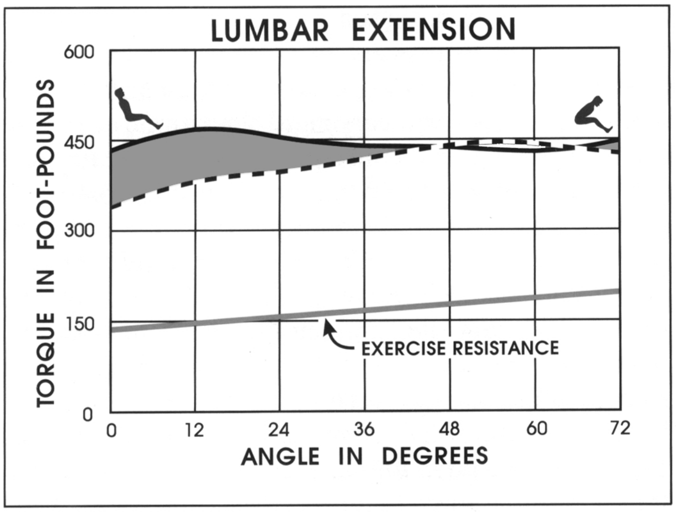
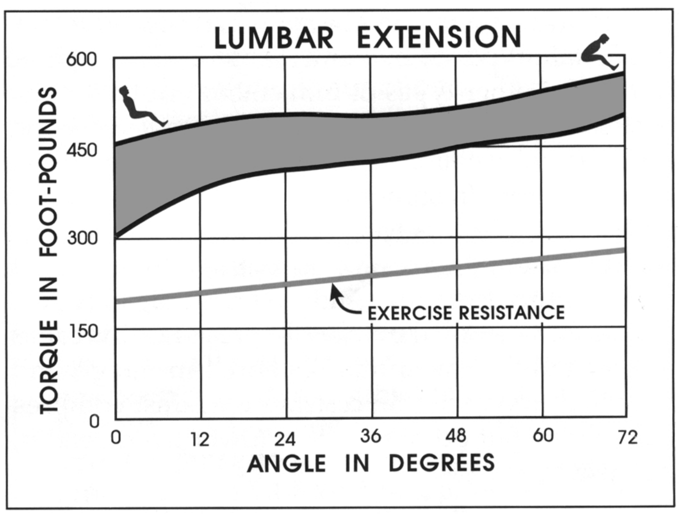



fig. 6




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 the 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.

## Apparent Changes in Muscular Fiber Type

Figure 5: 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 grey 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 average for an untrained man in the flexed position, which is usually the position of highest strength.

Figure 6: 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 upwards, 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, represent 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 in 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 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 Force

A Biomechanical Model, by Manohar Pahjabi, Ph.D., 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 on 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 physiological 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.”

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