

Shear Forces? or Sheer Nonsense?

by Ken Hutchins

Earlier this year, I published a two-page flyer regarding this subject. The brevity of that first article did not permit a thorough discussion. The following treatise is a comprehensive rendering.

In the early 1980s, Frank Noyes, MD, popularized the notion of *shear force* in knee function. He and his physical therapy staff performed and published cadaver studies that convinced the physical therapy and orthopaedic communities that force on the cruciate ligament (particularly the anterior cruciate) increases exponentially as the knee attains complete extension.

More specifically, Noyes states that the force on the anterior cruciate increases exponentially as the knee is extended its final 20-30 degrees. Given the function of the anterior cruciate to constrain the tibia to an arced motion rather than to an anterior translation, I am not surprised at this finding. However, I am alarmed that Noyes' work was taken out of the context of a cadaver study and taken by the orthopaedic community as conclusive with respect to the *in vivo* experience.

From these findings, Noyes and others further concluded that knee rehabilitation subsequent to cruciate repair should avoid extensional positions at or near (within 20-30 degrees) anatomical zero. Anterior cruciate repair is a delicate matter that deserves this benefit of doubt, although I believe that in most cases, this dictum is taken too far. There are other greater, looming, issues to consider that are almost always ignored in rehabilitation. Herein, I will elaborate.

Noyes' conclusion was yet further extended to the present philosophy and terminology of *Closed Chain vs. Open Chain Movements*. I will further demonstrate why this rehabilitation philosophy is specious and demonstrative of sophomoric notions.

Research Design Knee Function: Noyes obtained an intact adult human leg. He mounted the femur in a jig with pins in such a manner that the femur was roughly horizontal, while permitting the knee to freely articulate -- that is, the knee could freely articulate as much as a dead leg could be expected, rigor mortis notwithstanding. Thus, the lower leg was permitted to arc in a vertical plane.

Noyes attached a cable to the proximal end of the insertional quadriceps tendon. This cable ran parallel to the femur to exert force in the same general direction as had the quadriceps. He redirected, by way of a pulley, the cable to a pedal. Pedal depression, thus, enabled a technician to extend the cadaverous knee.

Data Generation: Noyes surgically implanted force transducers in-line with the cruciate ligaments. Such transducers enabled display of the force magnitudes. As the knee extended by depressing the pedal, Noyes obtained force readings from the transducers.

Criticism I presented a synopsis of Noyes's publication to Arthur Jones in 1981. His response was: "Do these researchers expect us to rehab the knee without bending the knee?" After all, the knee's function is to bend!

Although Noyes' work appeared straightforward, it avoided the following considerations:

- The cadaver study involved a cadaver! Cadavers have an abnormally low body temperature. Muscle sheaths in a dead limb are not of adequate temperature and lubrication to avoid abnormal levels of internal (both intramuscular and inter-muscular) friction. Normal synovial lubrication of the knees' articular surfaces is absent. (Noyes attempted to heat the cadaver to room temperature. This accomplished only a superficial degree of normalcy for the involved structures.)
- A cadaver's antagonist muscles are not operative to provide dynamic stabilization. Anatomists have always underscored that an overwhelming majority of knee stability is due to dynamic (muscular) rather than static (ligamentous) stabilizers.
- Noyes states that the force levels recorded were detected at "normal speeds" encountered in rehab. What the hell are "normal speeds?" Am I to assume that these are the same violent, irresponsible isokinetic speeds with which physical therapists commonly abuse their patients?
- Immediately post-surgical patients often have slight range of motion in their operative knee. It is unlikely that complete extension (or flexion) is attainable without resorting to violent acceleration -- the true source of excessive force in most movement.
- Shear forces are indeed involved during knee extension. But shear forces are involved in any movement. Such forces in the knee are meant to be contained by the cruciate ligaments. Without them the knee would not rotate very well during quadriceps contraction. Instead, the tibial plateau would tend to slide anteriorly and off the end of the femur. Arresting this tendency is the role of the anterior cruciate as a static stabilizer.

Considerations for Rehabilitation

Once people engage in a weight training regimen of some sort they have some degree of a protective fear in the back of their mind that they could get hurt. This is true. They could. To qualify further, however, this fear includes the notion that they might get hurt *because they attempted to lift a too-heavy weight (resistance)*. This notion is still true, but extremely unlikely. People, by and large, do not get hurt (if they do get hurt) because of a large resistance. They get hurt because of their behavior, because they jerk and heave and lunge and yank and jab -- all of which behavior is possible with a small resistance.

Newton's force law states that force is the product of mass and acceleration ($F=MA$). Since acceleration is a factor of the second derivative (calculus), acceleration is exponential. Therefore the speed of motion is a far greater thing to fear than the mass. (Actually, *getting to* speed and *getting from* speed is more serious than the speed itself, although the presence of anything other than a very slow speed of movement is a positive indication of excessive acceleration, especially when the overall excursion is relatively

short as in human movement. This is most completely detailed on pages 26-28 of *The SuperSlow Technical Manual*.)

Therefore, loading on the cruciates increases exponentially as the last 20-30 degrees of extension are performed; AND force increases exponentially as acceleration is increased. Note that *exponentially* does not mean *infinitely* as I am suspicious some naturally interpret. However, if any of the forces could become tantamount to *infinite*, acceleration is the quantum jump factor, NOT cruciate loading position.

Before I am as guilty as all the others who emphasize slow speed in exercise movements but who do not state what they mean by "slow," I must define slow. This is detailed in *The SuperSlow Technical Manual*, but here is a short guideline: In most applications, the positive phase of an exercise should occur uniformly in 8-12 seconds. The negative should occur in 4-6 seconds. Anything faster than a 6-second positive -- regardless of stroke length (arc) is too fast, either for safety reasons or for efficient fiber recruitment.

For 25 years I have observed the carelessness with which therapists and doctors instruct exercise. This statement also applies to what they do to or for themselves in their own personal training. With this experience, I can say that, with almost absolute certainty -- having never met Noyes nor his associates -- that neither Noyes nor his associates have ever witnessed proper rehabilitation with exercise. Nor have they considered the fact that violence to the anterior cruciate is almost totally and always the result of excessive acceleration, not the limb position and not the resistance involved. Most technicians on this subject are truly clueless.

Noyes' findings are valuable, however. They certainly influence me toward increased caution when administering care to a cruciate repair. But if you consider cruciate function, this, really, should not be necessary. You repair the anterior cruciate to reduce the slop out of the drawer sign, right? If you are mindful of Basmajian's points regarding the increased tension on the cruciates (both) during knee extension, then you should intuitively realize that forceful and complete extension might not be wise during the first few weeks of bone-plug mending.

But this heightened caution should not be so much to totally avoid complete extension as it is to avoid slamming into any extensional position, even a position on the border or somewhat short of the horrendously-feared last 20-30 degrees. If I am imposing a SuperSlow movement speed on the patient, he -- his body -- will tell me his limits. In the early stages of rehab, swelling and tenderness will in no way permit extreme extension by the affected knee in most patients, especially if they are using SuperSlow. And if I use the fast speeds almost always used by therapists, I cannot pinpoint the exact arc position of discomfort or apprehension on the part of the patient. The movement would occur so fast -- as if a musical glissando occurred. Not only do the intended-to-be-loaded muscle fibers seeming ask, "What was that?" as the movement sweeps by, but any problem areas are glossed over as well. Fast movement speed is simply sloven rehab technique. With fast motion, the therapist simply does not know what is going on.

As a result of Noyes's proclamation to avoid the last 20-30 degrees of extension for early-stage rehab of cruciate repairs, I witness patients who are told to avoid leg extension altogether and for all knee rehab and/or all exercise for all time. This is grossly overboard. These patients miss out on the most productive exercise they can do for most early-stage knee rehabilitation situations: leg extension. Leg extension is the only means to keep the extensional musculatures loaded and the only means to control the forces about the joint.

Closed-Chain vs Open-Chain Exercise

In the April 1992 issue of *Fitness Management* magazine an article appeared entitled, *Plane Sense*, by Gary Gray, PT, James A. Peterson, PhD, and Cedric X. Bryant, PhD. Gray is the originator of the *Chain Reaction Seminar Series* and a nationally recognized expert and speaker on the therapeutic applications of *closed-chain exercise*.

Gray, et al. begin their arguments pro *closed-chain* and con *open-chain* movements with an invocation from C.S. Lewis, a writer of Christian apologetics and children's fantasies. With nonsubstantive justification and definition, they next condemn *open-chain movement* -- an unnecessarily pedantic expression for *simple* or *single-joint* movement -- as ". . . unnatural, . . . non-functional, . . . counter-productive (injurious)."

They then *claim* a strong argument pro *closed-chain movement* -- an unnecessarily pedantic expression for *compound* or *multiple-joint* movement. For this they quote oblique support from Aristotle, albeit a well-known philosopher, but one who misled the civilized world regarding medicine, particularly regarding muscular/joint function from 322 BC until the arrival of Leonardo da Vinci. They use Aristotle to make a plea for *natural movements*. They conveniently fail to mention Aristotle's statement that the locomotion of mollusks was unnatural. The issue here is to define *natural*. It might seem unnatural to distinctly abduct your shoulder, then extend your elbow, then extend your wrist to reach for a pepper shaker at the table. Such a reach is most typically going to occur with a triplicate compound rotation of the involved joints. But if you were fending off an attack from behind you might naturally elbow the offense with a single-joint shoulder extension. Nevertheless, Gray et al. are desperately stretching for moot arguments here. Neither my argument nor theirs regarding *natural* has any relevance to rehabilitation.

What crucial background Gray et al. have overlooked is the fact that exercise is based on muscular and joint function and not on specific locomotor skill. It is expected, but obviously not guaranteed, that a physical therapy student would glean this from the emphasis on muscle/joint function in his schooling.

Then Gray goes on to quote Hans Seyle, MD, and to twist the intent of his theories on stress and adaptation. For this, Gray again emphasizes "artificial" and "unnatural" for which he has no substantive standard. He argues that patients often do not function painlessly in their daily activities though they elicit no pain during *artificial* rehab movements. He fails to consider the importance of skill specificity in his sophomoric

conclusion. Also, he suggests rehab activities such as one-legged step-ups and stair climbing that are absolutely worthless as well as potentially dangerous for rehabilitation purposes.

Therapists now like to speak of *functionality*. Recently, I overheard a therapist say that his interest was to increase the functionality of his patients, not their strength. On the contrary, the most important contribution to exercise made by Arthur Jones is the *Functional Ability* argument. Therein, Arthur explains that while there are six major and absolutely-essential factors of functional ability, only one of the six is truly productive -- muscular strength. Although the other factors are required, only the muscles produce movement of the body. An explanation of functional ability is available from *Media Support* (407-260-6204).

Another factor of functional ability is skill. Skill is often confused by therapists who attempt to design strengthening exercises to mimic vocational or locomotor tasks. Such skills are indeed necessary for functionality, but they have no place in exercises performed for muscular strengthening. Such a mixture of purpose compromises the principles of exercise (mechanical loading, inrading, and efficient stimulation), the principles of motor learning (positive, negative, and indifferent transfer), as well as the principles of safety (avoidance of undue acceleration=ballistic movement). Although none of these topics can be thoroughly detailed here, their substance is available from *Media Support*.

It is important to realize that Jim Peterson was/is a major player with *Randal Sports/Medical Products INC*, the maker of *Stairmaster*®. It is a natural assumption that climbing stairs is a good way to rehabilitate knees. This is a retreat to the days of running grandstands ordered by dumb football coaches. The coach should have been locked up. Instead, we honor his Neanderthal mentality by building convenience devices that simulate the same trauma to backs and knees. With good marketing and flashing electronics, the promoters have sold this nonsense as a technologically superior knee rehabilitation.

Rebuttal by Arthur Jones

In the June 1992 issue of *Fitness Management*, Arthur Jones blasted the Gray et al. article. In the April 1994 issue of *Iron Man*, Arthur detailed many MedX® measurements showing that compound movements simply did not *cut the mustard* when exercise was required in knee rehabilitation. He shares one story where the rehab patient observed the beneficial results prevented by the therapist's rabid devotion to Closed-Chain Philosophy and:

At that point, not being equally stupid, the subject told the therapist to go to hell and took charge of this own rehabilitation, started performing full-range [single-joint] exercise and quickly returned to a normal level of strength throughout the full range of movement. In fact, at the end of rehabilitation the injured leg was actually somewhat stronger than the normal leg.

Arthur does therein err with one emphatic statement. He states that simple movements (single joint) do not involve compression forces at complete extension. Due to any external resistance source this is true; but compression occurs in any completed extension due to the *screw-home* function of the knee. The most secure position of the knee is at complete extension. This is true, in part, because the cruciate ligaments twist on one another as extension completes. Thus likened to a dish rag twisted between your hands, its ends grow closer. Slamming into complete extension -- with either single or compound movements -- causes undue compression force. Such extreme violence can avulse the cruciates with concomitant fracturing of the bones. (Basmajian)

As Arthur notes, there is tremendous value in both compound and simple movements. But for certain purposes, especially early-stage rehabilitation, simple, single joint knee exercises -- knee extension exercises, knee flexion exercises -- are best. The safety crux in rehabilitation is control of the forces at the affected joint, which control is impossible when multiple-joint, compound movements are involved. Only with single-joint exercises can we precisely control the forces on the affected joint and stabilize the remainder of the body. Then, and only by moving slowly and pinning off for pain-free arcs, coupled with detailed, hands-on attention to the patient, can excessive and harmful forces be controlled.

The Closed-Chain proponents are oblivious to the fact that the real dangers of therapeutic exercise are the physical therapists. They have dined on an ego diet of isokinetics philosophy in their schools and elsewhere since the late 1960s. As a spuriously justified result, they abuse their patients with the violence of fast movement speeds. Make no mistake about it: This is nothing short of malpractice. It is high time for the therapists to rid their ranks of this nonsense.

The William Clancy Presentation

In 1981, I encountered William Clancy, MD, in Chicago. Clancy was an ambitious orthopaedic surgeon out to make a name for himself as a pioneer in sportsmedicine. Clancy was on his way to make a presentation at a regional meeting of the *American Physical Therapy Association*.

My encounter with Clancy occurred at the door of the elevators just prior to him going on stage. When he mentioned that he was presenting Noyes' work, he was in a big hurry. I knew that, like dealing with Arthur Jones, I had better come to the point and make it get attention. My chance of hitting my mark was slim but it was the only chance I had.

I told Clancy that the Noyes research was misleading and that he was committing a disservice to the medical community by giving it yet more publicity. He brusquely stated, "You are incorrect, Ken. Whatever the transducer says the forces are, is what the forces are." Of course, the truth could wait, Clancy's misguided presentation could not. He was not willing to hear any criticism that -- even though perhaps valid in its context -- it was invalid out of context.

Commercial Ramifications

The Shear Force Panic has had ubiquitous marketing effects. Many exercise equipment manufacturers attempt to capitalize on this panic with the promotion of compound movements for the legs *a la* closed-chain arguments. In 1990, Nautilus® introduced its *Next Generation Leg Press*. *The Winter Park Wellness Center* in Winter Park, Florida then cooperated with Nautilus as a showroom and as a facility for some of its Seminars. The Wellness Center permitted Nautilus to distribute an endorsement to the effect that the new leg press avoided harmful shear forces to the knees. *The Shear Force Panic* is still a popular issue as the *1993 Nautilus Equipment Catalog* makes the claim: ". . . the reduction of shear forces at the knee joint prevents strain on the anterior cruciate ligament, making this machine an excellent rehabilitation tool."

Although contrary to popular opinion, shear forces are not absent in compound movements. *Theoretically*, however, there is a rotational approach to loading the knee that avoids shear forces. It is known as the coupled movement arm. Coupled-movement-arm knee flexion machines are already being produced by *Nautilus®*, *Hammer®*, and *MedX®*. (I fostered their development though I am not yet satisfied with these machines.) Coupled-movement-arm knee extension machines are possible for early-stage rehabilitation but have never been developed. The coupled movement arm -- unlike common rotary-form movement arms that provide but do not impose rotation at the joint -- imposes rotation at the indicated joint. Theoretically, this imposed rotation completely relieves any translational components from the joint. Theoretically, the joint could rotate perfectly without the cruciates present. More information on this subject is obtainable from Media Support.

A Reasonable Approach

Shear force, or any force for that matter, should be considered excessive whenever it threatens the structural integrity of the affected tissues. Excessive force usually emanates from excessive acceleration. In the absence of excessive acceleration, a patient's complaints of pain must be analyzed on an individual basis.

The Shear Force Panic has distracted the therapist from the real issue of danger -- excessive acceleration -- thus subtly legitimizing his high-speed isokinetic practices. Such unwarranted fear has also distracted the therapist away from the essence of rehabilitation: progressive muscular strengthening with commensurate and functional range of motion. This panic has resulted in a gross disservice to thousands of patients: scaring them away from the best exercise for early-stage rehabilitation. Movements such as knee extension and knee flexion are often the treatment of choice. For early stage rehabilitation, negative-only protocol is often best. *SuperSlow Protocol* should be used for all else.