**The Effects of Manual Therapy on Connective Tissue**
A Joseph Threlkeld
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# The Effects of Manual Therapy on Connective Tissue

*The purpose of this manuscript is to examine the known and theoretical mechanical effects of therapeutic manual techniques on the connective tissue (CT) of joints and fasciae. Typical CT structures that could be influenced by manual techniques will be discussed. The behavior of CT under loading and the influence of immobilization on CT will be examined. The forces developed during manual techniques will be described, and their potential effects on the physical properties of CT will be discussed. Research priorities regarding the effects of manual therapy on CT will be outlined. [Threlkeld AJ. The effects of manual therapy on connective tissue. Phys Ther. 1992;72:893–902.]*

**A Joseph Threlkeld**

**Key Words:** *Connective tissue; Immobilization; Joints; Kinesiology/biomechanics, general; Manual therapy.*

Manual therapy encompasses a broad range of techniques that are used to treat neuromusculoskeletal dysfunctions. Manual therapeutic techniques are used to relieve pain and to increase the mobility of joints.[1,2] The techniques that are specifically utilized to affect connective tissues (CTs) could be generally categorized as either stretching or compression and include massage, fascial/tendon stretching, traction, and articulation/thrust (ie, small-amplitude movements of a joint) techniques. In most cases, patients with joint dysfunction have both pain and loss of motion. Therapeutic intervention is usually designed to treat both problems. This article is primarily intended to deal with the effects of manual therapy on CT structures that are producing pathological joint motion via abnormal CT shortness or diminished CT mobility. The neurophysiology of pain originating from joints and the putative effects of manual treatment on joint pain are outside of the scope of this manuscript.

Abnormal shortness of muscles and tendons that cross a joint can restrict joint mobility, particularly the gross relative position of body segments known as osteokinematics. *Osteokinematics* refers to the motion of adjacent bones with respect to one another and ignores the subtle motions occurring between the articular surfaces.[3] Clinical goniometry techniques usually document osteokinematic motion. Because of the combination of contractile and noncontractile tissues in musculotendinous structures, long-term stress using traditional exercise, long lever-arm stretching techniques, and massage are often used when a therapeutic change in the length of muscle is needed. In contrast, graded manual therapeutic techniques are often directed toward restoring the subtle motions between joint surfaces—the arthrokinematic motions of spin, glide, and roll.[1–4] Graded mobilizations are externally imposed, small-amplitude passive motions that are intended to produce gliding or traction at a joint.[1,5] The graded mobilizations that are conducted toward the beginning of the available arthrokinematic range of motion (ROM) are intended to treat pain through activation of neural structures, whereas graded mobilizations applied at the end of the available arthrokinematic ROM are intended to elongate CT.

Typically, the CT structures that restrain or limit arthrokinematic joint excursions are ligaments, joint capsules, and periarticular fasciae. These structures provide resistance to forces acting on joints, particularly tensile and shear forces. The muscles and CT act in concert with the mechanical effects of articular shape, articular orientation, and fibrocartilaginous structures (eg, menisci) to determine the arthrokinematic and osteokinematic ROM. One of the principal uses of manual therapy is to produce elongation of the CT structures that may be abnormally restraining arthrokinematic motion.[1,2]

## Mechanical Behavior of Connective Tissue

One of the aims of manual therapy is to permanently elongate soft tissues

AJ Threlkeld, PhD, PT, is Associate Professor, Department of Physical Therapy, Creighton University, California Street at 24th, Omaha, NE 68178 (USA). He was Associate Professor, Division of Physical Therapy, University of Kentucky Medical Center, Lexington, KY, when this article was written.

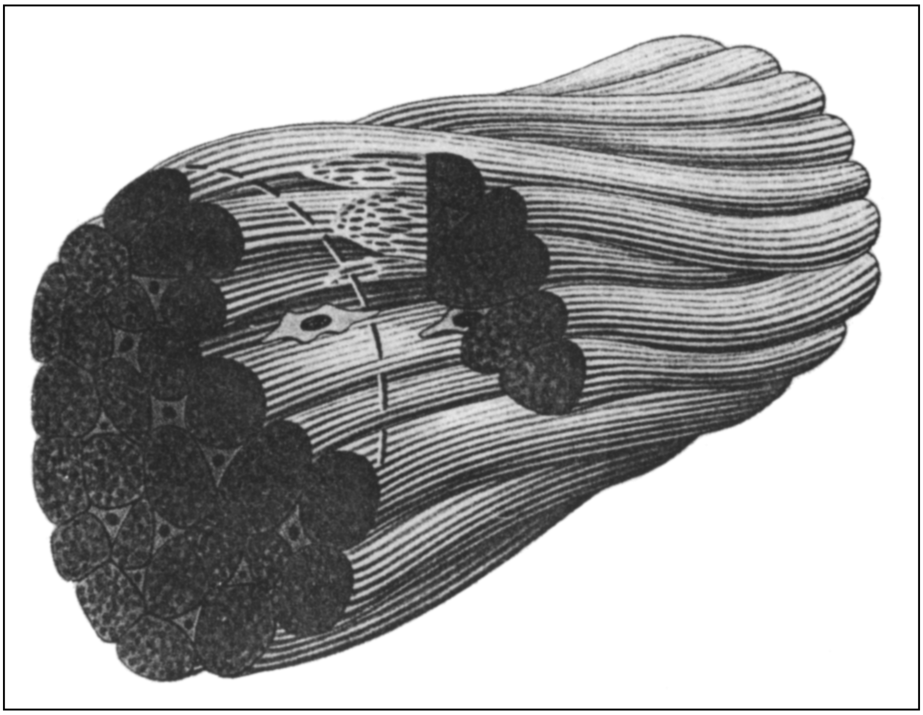

**Figure 1.** *Collagen fibers in a tendon are grouped in bundles that are relatively parallel. (Reprinted with permission from Williams PL, Warwick R, Dysan M, Bannister LH. Gray's Anatomy. 37th ed. New York, NY: Churchill Livingstone Inc; 1989:69.[8])*

that are restraining joint mobility through the application of specific external forces.[1,2] Some of the biological properties of normal and abnormal CTs that alter their reaction to loading will be described in order to better understand the response to manual therapy of heterogeneous articular structures and of patients with CT pathology. The mechanical responses of typical CT structures to loading under laboratory conditions will be reviewed and will provide a framework for a discussion of the clinical effects of manual therapy on articular and periarticular CT structures.

## Connective Tissue Structure

The basic constituents of most biologic tissues are cells, fibers, and ground substance. Dense regular CT is a histologic category of CT that includes ligaments, tendons, fasciae, and aponeuroses. These dense CT structures all share similar elements but differ in mechanical characteristics, primarily because of the arrangement and various proportions of their basic constituents (eg, tendons, ligaments, fasciae).[6]

Ligaments and tendons are similar because most of their collagen content is aligned in roughly parallel bundles, with a few fine elastic fibers between the bundles. Small collagen bundles are joined together into larger bundles by loose CT to form the anatomical structure of a tendon or ligament (Figs. 1, 2). The collagenous bundles in tendons are arranged somewhat more regularly than the bundles in ligaments, but bundles in both structures may have some undulations or "crimping" when not under tensile loading (Fig. 3).[6,7] Tendons and ligaments have sparse, flattened fibroblasts that are scattered throughout their structure and have little ground substance. Their predominant structural component is collagen, although the ligamentum flavum of the axial skeleton has a much higher content of elastin fibers than do other ligaments.[8,9]

Fasciae and aponeuroses also have collagen bundles, but the bundles are organized into multilayered sheets or lamellae.[6,8] The bundles within individual layers are roughly parallel but often have some undulations or waviness. Adjacent layers may not have the same fiber bundle direction, although fibers will often pass between adjacent layers as well as into adjacent loose CT. The fibroblasts that are found in fasciae and aponeuroses are sparse and variable in shape. Ground substance and elastin content is low in fasciae.

The presence of waviness or crimping in the normal collagen bundles represents a variable amount of slack. This slack must be taken out by a tensile force before any individual bundle of collagen is placed on stretch. The result of the crimping in conjunction with the variability in bundle alignment is a collagenous structure with subunits that are loaded asynchro-

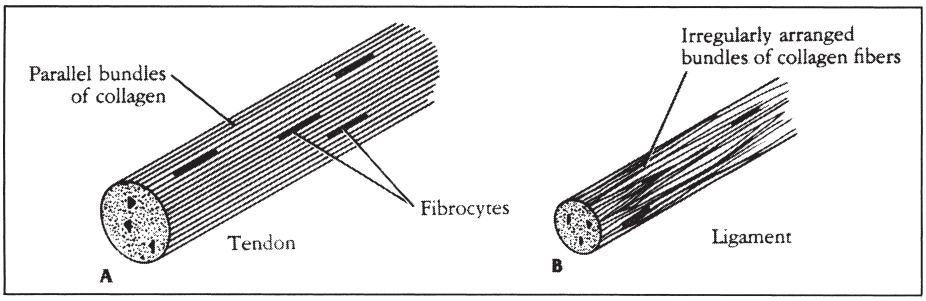


**Figure 2.** *The bundles of collagen in a tendon are mostly parallel (A), whereas the bundles in a ligament (B) may be arrayed in more one than one direction. (Reprinted with permission from Snell RS. Clinical and Functional Histology for Medical Students. Boston, Mass: Little, Brown & Co Inc; 1984:125.)*

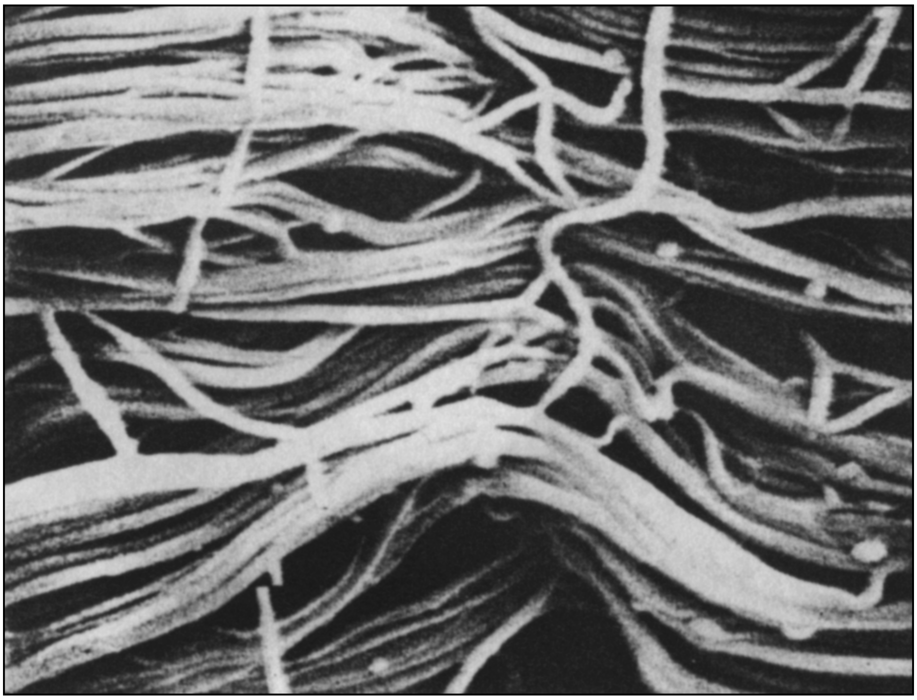

**Figure 3.** *Scanning electron micrographs of collagen fibers from human knee ligaments at a magnification of × 10,000. When the fibers are not under load, they may be wavy or crimped. When the fibers are under tensile load, the crimping tends to straighten out. (Reprinted with permission from Kennedy JC, Hawkins RJ, Willis BB, Danylchuk KD. Tension studies of human knee ligaments: yield point, ultimate failure, and disruption of the cruciate and tibial collateral ligaments. J Bone Joint Surg [Am]. 1976;58:350–355.[7])*

nously. The bundles that are most closely aligned parallel to the direction of tensile stress and have the least slack (crimping) will be the first to resist tensile loading. The remaining bundles of collagen will come into play as further deformation takes out additional slack.[7,10–12] Only after many of the bundles are placed on stretch does the CT structure as a whole begin to provide significant resistance to the tensile force. The resistance of a tissue to deformation can be graphically represented on a stress-strain curve. The load is plotted on the y-axis, and the resulting deformation is plotted on the x-axis. The slope of the curve indicates the stiffness of the material, that is, the resistance of the material to deformation.[13] The lack of significant resistance to tension while most of the collagen bundles are still slack is thought to be the basis of the "toe" region of a stress-strain curve (Fig. 4). Because of the asynchrony, bundles must be free to effectively slide past one another in order for the entire CT structure to equilibrate with the external tensile force. If the bundles cannot slide freely, then the brunt of the tension must be resisted by the subset of the bundles that have the least slack and the most parallel alignment to the tensile force.

Connective tissue has the greatest resistance to stress when it is loaded in tension, parallel to the primary direction of its collagenous fiber component.[10,11] Indeed, collagenous fibers within CT appear to be oriented along the long axis(es) of the principal tensile physiological loads placed on the tissue in vivo. Experiments on CT remodeling suggest that fiber orientations and cross-linkages are strongly dependent on the applied loads.[14–17] Ligaments may possess several distinct segments. The collagen bundles within each segment are essentially parallel, but different segments are not aligned with one another. This arrangement provides the potential to place individual segments under differential tensile loads, depending on the orientation of the force with respect to the segment. For example, when the anterior cruciate ligament has a tensile load, selected ligamentous segments resist anterior translation of the tibia on the femur, depending on the degree of knee flexion and rotation.[18]

### *Resistance of Connective Tissues to Mechanical Stress*

Periarticular CT structures are typically tested under tensile loading to determine their maximal mechanical behavior. Tensile testing of CT produces a stress-strain curve that represents the load and resulting CT deformation, and this curve has been divided into several functionally important regions (Fig. 5).[19,20] The clinical test region is the same as the toe region shown in Figure 4 and represents the level of load and deformation at which crimping is being taken out of the CT structure. The presence and shape of the stress-strain curve in the toe region is variable and dependent on the internal structural organization of the tissue. The more regular and parallel the collagenous fiber organization, the shorter the toe segment. In the terminology of manual therapy, the act of elongating CT through the toe region is known as "taking out the slack."[2,5] The graded mobilizations that are intended primarily to relieve pain but not to elongate CT are supposedly conducted in this range (eg, Maitland grades I and II).[5]

The physiologic loading region of the stress-strain curve shown in Figure 5 represents the range of forces that usually act on CT in vivo and implies that primarily elastic deformation occurs at these loads. The region of microfailure overlaps the end of the physiologic loading zone. *Microfailure* represents the breakage of the individual collagen fibers and fiber bundles that are placed under the greatest tension during progressive deformation. The remaining intact

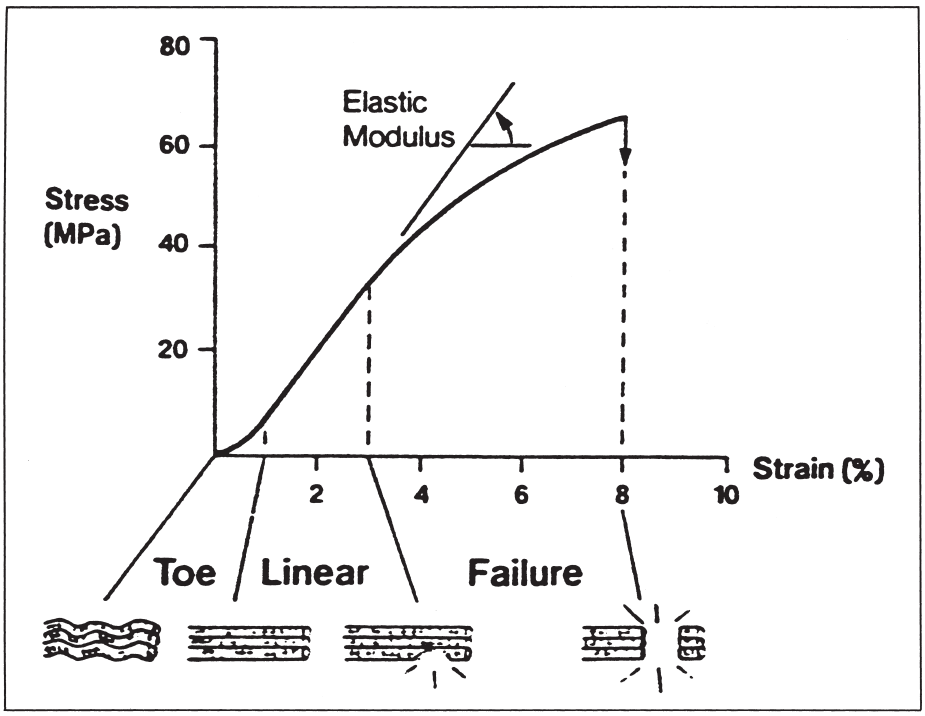


**Figure 4.** *This idealized stress-strain curve for collagen graphically shows the progression of changes as increasing tensile force (stress) produces ever greater fiber deformation (strain). In the toe region, very little stress produces a relatively large percentage of deformation as the crimping is taken out of the collagen. Permanent tissue elongation (plastic deformation) does not occur until the latter part of the linear region of the curve when some fiber breakage occurs. The elastic modulus is the slope of the linear region of the stress-strain curve. (Reprinted with permission of Lawrence Erlbaum Associates Inc from Butler DL, Grood ES, Noyes FR. Biomechanics of ligaments and tendons. Exerc Sport Sci Rev. 1978;6:125–181.)*

fibers and bundles that may have not been directly aligned with the force or those that had more intrinsic length absorb a greater proportion of the load. The result is progressive, permanent (plastic) deformation of the CT structure. If the force is released, the broken fibers will not contribute to the recoil of the tissue. A new length of the CT structure is established that reflects the balance between the elastic recoil of the remaining intact collagen and the resistance of the intrinsic tissue water and glycosaminoglycans to compression. Microfailure is a desired outcome of some manual stretching techniques that are intended to produce permanent elongation of CT structures. It is important to note that a low level of CT damage *must* occur in order to produce permanent elongation. The collagen breakage will be followed by a classical cycle of tissue inflammation, repair, and remodeling that should be therapeutically managed in order to maintain the desired tissue elongation. The use of modalities, compression, elevation, and directed—but limited—application of force may improve the final results through modulation of the inflammatory cycle.

Plastic deformation should not be confused with the phenomenon of creep (Fig. 6). When a load is applied to a viscoelastic tissue over a prolonged period, the tissue will progressively deform until a new resting length is achieved. If the load was within the elastic limits of the tissue, the tissue will gradually return to the original resting length after the load is removed. In biological tissues, this phenomenon primarily represents the redistribution of water from the tissue to the anatomical spaces surrounding the tissue.[20] Some of the elongation of tissues that results from manual stretching and massage techniques may reflect nonpermanent creep deformation. Clinical research designs examining manual therapy techniques should incorporate several repeated measurements of elongation up to 24 hours after the application of the technique in order to detect this phenomenon.

Connective tissues demonstrate viscoelasticity, a material property whereby the deformation (strain) that results from a load (stress) will vary as the rate of loading is changed (Figs. 6, 7).[7,20,21] Connective tissue that is loaded more quickly will behave more stiffly (will deform less) than the same tissue that is loaded at a slower rate (Fig. 7). In addition, the structure will have a higher ultimate strength (ie, the highest load applied before failure) at a higher loading rate than at a lower loading rate. The property of viscoelasticity may be exploited in joint mobilization techniques. For example, one method of mobilizing a specific lumbar facet joint is to rotate a patient's upper trunk until all of the thoracic and lumbar facet joints cranial to the desired lumbar facet level are at or near maximal rotation. The same strategy is applied below the level of the targeted lumbar facet by rotating the pelvis in the direction opposite that of the upper trunk rotation until all lumbar joints below the target lumbar facet are fixed in rotation.[22] Ideally, the slack is taken out of the CT rotational restraints of the facet joints above and below the targeted lumbar facet. If the therapist then applies simultaneous rotary force to the thorax and the pelvis in the directions originally used to take the slack out of the structures of the thoracic and lumbar joints, the rotary force is transmitted through the stretched CT to arrive at the lumbar facet of interest with little loss of energy or force/time characteristics. The more rapidly the therapist applies the rotational force, the more stiffly the intervening CT will behave and the less the force will be attenuated when it reaches the target facet.

All articular and periarticular CTs have a similar composition: large numbers

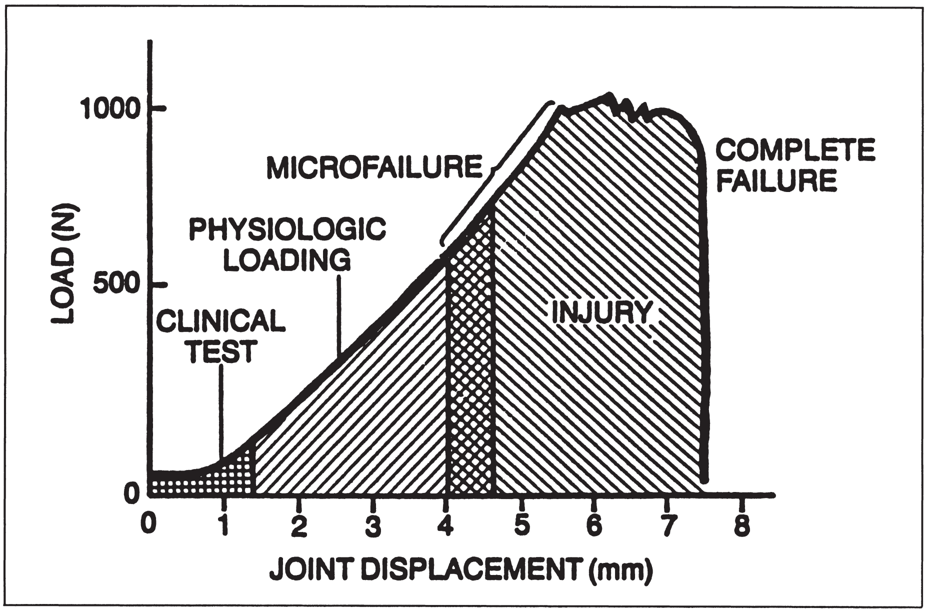


**Figure 5.** *Several clinically important zones are indicated on this stress-strain curve of a human anterior cruciate ligament. The clinical test zone represents the load and resulting displacement normally experienced by the ligament during an anterior drawer test. The physiologic loading zone indicates that most forces generated during daily activities load the ligament in the linear region of the curve and produce nonpermanent (elastic) deformation but that microfailure (plastic deformation) occurs at the highest physiologic loads including the injury zone. The region of overlap of the microfailure zone with the physiologic loading zone will vary with the structure and composition of the ligament under consideration. (From M Nordin and VH Frankel: Basic Biomechanics of the Musculoskeletal System, 2nd edition. Philadelphia, Lea & Febiger, 1989. Reprinted with permission.)*

of collagen fibers coupled with relatively low ground substance content and few cells. The mechanical behavior of ligaments and tendons can be considered to be representative of idealized periarticular CT placed under loading. The ultimate strengths of other common CT structures are listed in the Table. The ultimate strength of spinal ligaments has been less systematically studied. Panjabi and White[23] indicate that the ultimate strength of spinal ligaments ranges from 35 to 450 N. Within a region of the spine, the strongest ligament is generally the anterior longitudinal ligament and the weakest ligament is the interspinous ligament, with the strength of the capsular ligaments, the posterior longitudinal ligament, and the ligamentum flavum falling in between.[23] Noyes et al[24] estimated that macrofailure of CT occurs at approximately 8% elongation of the CT structure but that microfailure begins at approximately 3% elongation. If I make the simplifying assumption that the stress-strain curve is linear and use the elongation estimates of Noyes and colleagues for microfailure and macrofailure, CT would begin to experience microfailure at around 224 to 1,136 N (24–115 kg). This gross approximation of the load necessary to cause microfailure (some permanent elongation) can be used to make some educated guesses about how effective the typical forces encountered in manual therapy will be in stretching CT.

### *Effect of Injury and Immobilization on Connective Tissue*

The classic sequence of inflammation, repair, and remodeling follows CT injury.[25] The long-term effects of reduced stress (immobilization) on CT structures are similar to acute injury, although the process is prolonged and the acute inflammation stage is absent.[10,14,16] The end result of the healing/reorganization process in CT is that the tissue has a more irregular arrangement; contains proportions of collagen types that are different from normal; has a lower water content; and contains more random cross-links between fibers, fiber bundles, and adjacent tissues.[10,14–16] Periarticular CT that has been removed from immobilized limbs has been described as "woody."[10] As the collagen fibers are more randomly arranged with respect to the testing force, the fibers must resist forces that are not aligned with their long axes (shearing forces)—a task for which collagen is not structurally prepared, as reflected by reduced ultimate strength.[10,11] In addition, the loss of water diminishes the ease with which the collagen bundles might slide past one another, which has the effect of reducing the ability of the various collagen bundles to align and equilibrate with the applied stress.[10] The end result of both inflammation and immobilization is a remodeled CT with lower tensile stiffness and a lower ultimate strength than normal tissue.[10,14–17] This weakening is caused by the more randomized collagen fiber direction, by the inability of collagen bundles to easily slide past one another (cross-linking and loss of water), and possibly by the substitution of collagen types that are less strong than the original collagen.

## Application of Manual Therapy to Connective Tissue

When manual therapeutic techniques are used to decrease joint stiffness, external forces or torques are applied to anatomical structures with the intent of permanently changing the length or mobility of CT. The resting length of CT is changed through plastic deformation. The mobility of CT is changed by breaking some of the links between adjacent CT bundles. Mobility might also be improved by restoring the interstitial fluid content of CT structures to normal levels, thereby reestablishing normal frictional resistance between the bundles and adjacent structures.

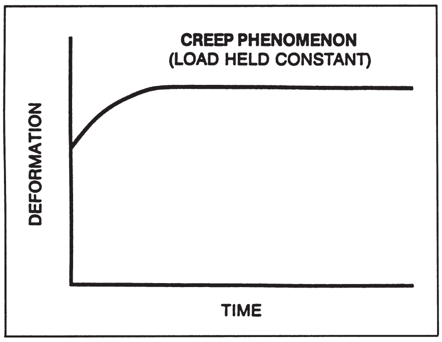


**Figure 6.** *The curve shows the amount of deformation that occurs over time when a constant load is applied to a ligament. The ligament deforms considerably at first. Elongation tends to plateau after 6 to 8 hours, although very gradual deformation can continue for months if the load is continued. The creep phenomenon is characteristic of viscoelastic materials and occurs at loads well below those of the linear region of a stress-strain curve. Creep deformation is not permanent, and the tendon will slowly resume its original length after the load is removed; this response is called a "damped elastic response." (From M Nordin and VH Frankel: Basic Biomechanics of the Musculoskeletal System, 2nd edition. Philadelphia, Lea & Febiger, 1989. Reprinted with permission.)*

Fibrocartilaginous blocks have been proposed as a cause of mechanical intervertebral joint stiffness that is not related to CT shortening or CT immobility.[26–28] The most commonly cited examples of such blocks are fibrocartilaginous tabs of material on the inner surfaces of facet joint capsules (eg, meniscal inclusions or meniscoids).[26–28] In these cases, the goal of manual therapy is often to alter the relative positions of the joint surfaces and the fibrocartilage block to restore normal gliding of the facet surfaces and reduce aberrant capsular stretching.[28] The CTs that form the block are not essentially changed by manual therapy but merely returned to a configuration that does not block or derange facet joint motion. The actual prevalence of joint inclusions in the population and the effect of manual techniques on these inclusions have not been established. Undoubtedly, there are multiple articular and periarticular CT structures in addition to meniscal inclusions that are affected by manual techniques, any or all of which may contribute to a change in a patient's symptoms following mobilization.

### External Forces Produced During Manual Therapy

Manual therapy is often used to produce a desirable amount of plastic deformation of CT (microfailure of ligaments, fasciae, and so on) and to produce movement of one joint surface with respect to another. Both of these goals require that the medical practitioner apply an external force to the patient. In order for the technique to be safe, effective, and reproducible, the magnitude, velocity, and rate of application of the force must be imparted within relatively narrow limits. Despite the widespread use of manual techniques, the external forces that are actually applied during manual therapy are poorly documented. Lee et al[29] reported that an average peak force reached during an idealized posterior-to-anterior (P-A) mobilization of the L3 vertebra was approximately 33.3 N (3.4 kg). The authors used a mobilization technique that was intended to stretch the spinal tissue until resistance was reached (ie, Maitland's grade II[5]). Matyas and Bach[30] reported peak forces of up to 200 N (20.4 kg) during mobilization of the spine. No generally available published studies have provided complete force versus time records for common mobilization or thrust techniques.

In order to obtain some limited data for discussion purposes, two therapists who have more than 5 years of clinical experience each and who are considered by the local physical therapy community to be "manual therapists" were asked to perform P-A thoracic mobilizations. The data-collection instrumentation they used was similar to that used by Lee et al.[29] In brief, a healthy adult volunteer lay prone on a rigid platform that in turn was resting on a force plate. The therapists performed grade I and grade IV oscillatory mobilizations and a grade V single thrust manipulation on the midthoracic spine of the volunteer. The definitions of the graded mobilization follow the system outlined by Maitland.[5] Both of the therapists utilized a two-handed technique, applying force through their hypothenar eminences onto either side of the subject's spine immediately over the lateral ends of a selected pair of thoracic transverse processes. The grade V thrust was applied to one tip of a thoracic transverse process and simultaneously to the contralateral tip of the transverse process of the adjacent thoracic vertebra to produce a rotary motion between the two segments. No feedback was provided to the therapists during the performance of the maneuvers. Vertical ground reaction force data from each technique were collected for 2 seconds. The analog signals from the force plate were digitized and sampled at a rate of 2,000 Hz.

The data from the mobilizations are shown graphically in Figures 8 through 10. The frequency and amplitude of oscillatory forces in the grade I and IV mobilizations were fairly repetitive within each therapist and within each technique. Therapist 1 performed the oscillatory techniques with consistently higher frequencies and amplitudes than did therapist 2. Therapist 1 also produced a more forceful grade V manipulative thrust with a higher rate of application than did therapist 2. Compared with the average peak force of 33.3 N (3.4 kg) from the grade II lumbar mobilizations reported by Lee et al,[29] the thoracic mobilizations in this pilot study produced much higher peak forces (ie, approximately 4–6 times as much for the thoracic grade I, 9–15 times as much for grade IV, and 14–17 times as much for grade V). The highest P-A force developed in this pilot experiment was 578.2 N (59 kg) during the grade V maneuver. Because the thoracic transverse processes are associated with the rib cage, the therapists may have applied more force to overcome the additional resistance to movement provided by the ribs. Direct comparisons are difficult because of the different anatomical regions mobilized, but the enormous disparity in the forces measured in these re-

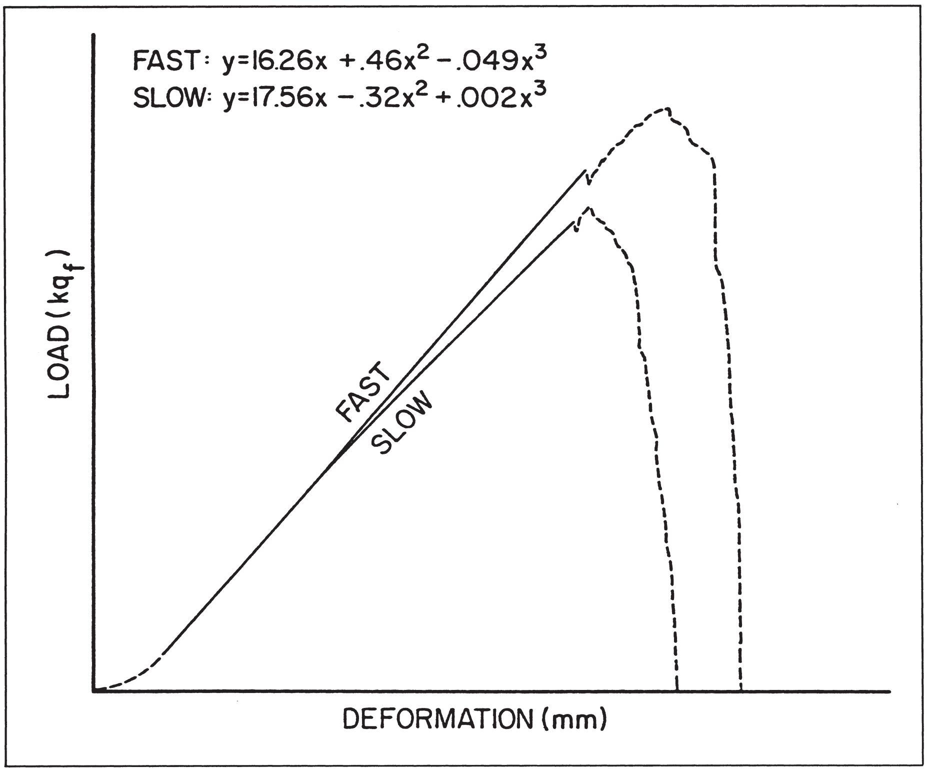


**Figure 7.** *The pair of stress-strain curves represent the average behavior of 17 pairs of anterior cruciate ligaments; one knee of the pair was loaded at a fast rate, and the other knee was loaded at a slow rate. After reaching the upper half of the linear region of the stress-strain curve, the group of ligaments loaded at a fast rate deformed less at a given load and sustained a higher load before breaking than did the group of ligaments loaded at the slow rate. (Reprinted with permission from Noyas FR, DeLucas JL, Torrik PJ. Biomechanics of anterior cruciate ligament failure: an analysis of strain-rate sensitivity and mechanisms of failure in primates. J Bone Joint Surg [Am]. 1974;56:236–253.[21])*

**Table.** *Comparison of the Mean Ultimate Strengths of Selected Collagenous Tissues*

| Structure | Author | Mean Ultimate Strength[a] |
|---|---|---|
| Anterior cruciate ligament | Kennedy et al[7] | 627 N (64 kg) |
| | Noyes et al[24] | 1,730 N (175 kg) |
| Posterior cruciate ligament | Kennedy et al[7] | 870 N (89 kg) |
| Tibial collateral ligament | Kennedy et al[7] | 667 N (68 kg) |
| Bone-tendon-bone unit including mid one third of patellar tendon (14 mm width) and bony insertion sites | Noyes et al[24] | 3,028 N (306 kg) |
| Semitendinosus tendon | Noyes et al[24] | 1,297 N (121 kg) |
| Gracilis tendon | Noyes et al[24] | 848 N (86 kg) |
| Tensor fascia lata tendon (16 mm width) | Noyes et al[24] | 623 N (63 kg) |
| Distal iliotibial band (18 mm width) | Noyes et al[24] | 657 N (67 kg) |

[a]All tissues were tested at a strain rate of approximately 8.3 to 8.5 mm/s.

ports underscores the need for further investigation.

A serious deficiency exists in the manual therapy literature regarding the forces used to move joints and to stretch tissues. The outcome of manual techniques relies on the skillful application of forces—forces with very definite magnitudes, velocities, accelerations, and directions coupled with specific anatomical sites of application. One could imagine that force could vary depending on the technique used, the region treated, the type of pathology present, and the somatotypes of both patient and therapist. The cyclicity, physical displacement, velocity, and acceleration parameters of manual thrust techniques applied to human subjects are largely undocumented. No published estimates exist for the external forces developed during friction massage, soft tissue stretching, or manual distraction techniques. Detailed documentation of these forces is necessary if the mechanical effects of various manual techniques are to be evaluated in light of physical properties of the target tissues. Additionally, the teaching of manual techniques would be greatly facilitated if standards existed against which a student's performance can be measured.

One of the components of manual thrust techniques is to preload a tissue by "taking out the slack" prior to beginning therapeutic movement. This component is often referred to as "reaching the first point at which resistance is felt," a point sometimes called "R1" in the manual therapy literature.[5,29] Theoretically, the therapist is attempting to stretch the CT through the toe region of the stress-strain curve in order to reach some point at which the stiffness of the CT changes markedly (eg, a change in slope of the curve). The same concept is often used in soft tissue stretching techniques by alternating active patient muscle contraction with passive stretching. The end result should allow the collagen fiber crimping to be removed from the CT and for some amount of creep deformation to occur. These are temporary lengthening phenomena demonstrating a damped elastic response and can easily be misinterpreted as permanent lengthening. Plastic deformation does not take place until the forces within the tissue reach a higher level. The level of force application necessary to obtain *permanent* deformation of periarticular CT is the topic of clinical debate and will remain so until well-controlled scientific studies are carried out.

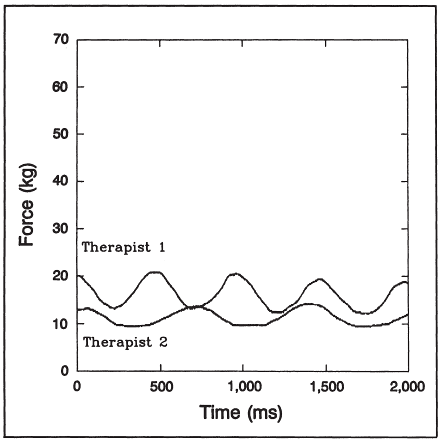


**Figure 8.** *Grade I thoracic mobilization performed by two manual therapists. Therapist 1: mean force=158.8 N (16.2 kg), range=117.6–205.8 N (12–21 kg); frequency=2 Hz. Therapist 2: mean force=110.7 N (11.3 kg), range=91.1–140.1 N (9.3–14.3 kg); frequency=1.5 Hz.*

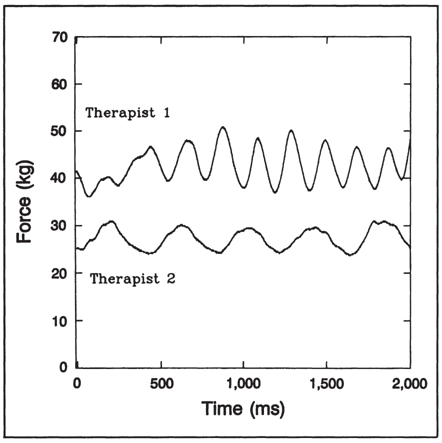


**Figure 9.** *Grade IV thoracic mobilization performed by two manual therapists. Therapist 1: mean force=417.5 N (42.6 kg), range=352.8–499.8 N (36–51 kg); frequency=5.5 Hz. Therapist 2: mean force=267.5 N (27.3 kg), range=231.8–303.8 N (23.6–31 kg); frequency=2.5 Hz. Note: The descriptive data were extracted only from data collected between 1,000 and 2,000 ms.*

In some cases, oscillatory manual techniques are applied to CT with the goal of guiding tissue remodeling and repair and decreasing the randomized arrangement and interlinking of new collagen fibers.[31] Research supports the concept that the application of force to CT during tissue healing and remodeling can improve the extensibility and strength of the tissue.[7,10–12,14–17,19] What is less clear is whether the small "dose" of force that can be imparted during relatively infrequent therapeutic mobilizations will elicit a remodeling response that is more appropriate to the demands placed on the tissue. Will mobilization in combination with prescribed activity be more effective than activity alone? The minimal effective dosage of force has not yet been defined nor has the actual distribution of externally applied manual forces within complex biological structures been delineated. The theoretical concept of guiding CT healing and remodeling through mobilization is supported by the literature; however, research has not yet established whether the application of manual techniques actually accomplishes this goal.

## *Internal Forces Produced During Manual Therapy*

If 100% of an externally applied force could be transmitted to the long axis of a selected portion of a CT structure, then it could be presumed that forces commonly produced during manual therapy could produce permanent elongation. For example, based on data from the Table, an 18-mm-wide segment of the distal iliotibial band would begin to undergo microfailure at 246 N (25 kg) and macrofailure at 657 N (67 kg). These forces are well within the ranges of forces encountered during thoracic mobilization (Figs. 8–10). The external forces, however, are *not* direct and are not completely transmitted to a preselected segment of a CT structure. The original externally applied force is dispersed throughout a region. Each affected tissue or structure may be subjected to a component of the total force with a markedly different magnitude and direction. The external force is distributed throughout a target structure as well as adjacent tissues. Consider, for example, the difference between the ultimate strength of the combined bone-tendon-bone unit of the patellar tendon (3,028 N) and the strength of the isolated anterior cruciate ligament (1,730 N) (Table). The composite material found in intact biological structures will have a much different response to force than will an isolated homogeneous tissue sample.

There is very little research that explores the details of force transmission through a fully intact anatomical region, and few attempts have been made to construct a mathematical model of the spine's response to manual mobilizing forces. Research by Giovnelli et al[32] showed that transverse forces on a lumbar spinous process produced a change in the intracapsular pressure of facet joints of the mobilized vertebra, with a much smaller change in intracapsular pressure in adjacent facets. A simple theoretical model of the forces and moments experienced by the thoracic and lumbar vertebrae in response to the application of a 200-N force was published by Lee.[33] The articles by Lee and by Giovnelli et al both support the premise that the physical details of forces applied to the spine are critical in determining the final effect. The task of delineating the CT response to specific forces is even more complex when one considers that CT structures have a lower resistance to forces when loads are not aligned parallel to the collagen fiber direction (shear stress).[20,21] No firm bench-testing data exist on the mechanical performance of most CT structures under specific shearing loads. The real-world distribution, magnitude, direction, and time course of the internal and external forces involved in manual therapy have yet

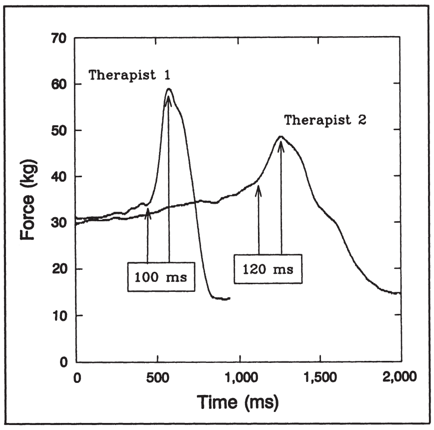


**Figure 10.** *Grade V thoracic mobilization performed by two manual therapists. Therapist 1: peak force=578.2 N (59 kg), time from beginning of high-velocity thrust to the peak force=100 ms. Therapist 2: peak force=476 N (48.57 kg), time from beginning of high-velocity thrust to the peak force=120 ms.*

to obtain a satisfactory or comprehensive description.

## Summary and Recommendations for Further Study

Much of the work in mechanical testing of CT has concentrated on the tensile strength of isolated tissue samples. Most of this research has been generated in the area of ligament replacement and in describing the ultimate strength of spinal ligaments under isolated conditions. Very little published information exists on the stress-strain behavior of combined articular and periarticular CTs or on the behavior of CT under shearing loads. In addition, the three-dimensional dispersion of forces within relatively intact anatomical regions of the human body has yet to be explored. This line of research would provide the theoretical guidelines against which the techniques of manual therapy could be compared. This area of research could be pursued in a collaborative fashion with the appropriate engineering, mathematical, and anatomical scientists.

There are almost no published reports of the external forces, displacements, velocities, accelerations, and vectors generated in even the most popular manual techniques. Physical therapists currently have wide access to clinical biomechanics laboratories equipped with the instrumentation needed to describe these variables. A large descriptive base of biomechanical data could be accumulated on manual therapy in a relatively short period of time. This is an area that should receive intense scrutiny in the physical therapy research community. What are the forces involved? What is the intratherapist and intertherapist reliability? What are the physical differences in the various approaches to manual treatment? Are experienced practitioners essentially different from novices? These data would provide the basis for categorizing and standardizing techniques to permit controlled, prospective efficacy studies. In addition, the information would be extremely valuable in the education of students in the nuances of manual therapy.

## Conclusions

The ability of manual therapy to affect CT has some support in the basic literature of mechanical tissue testing and CT remodeling. Physical forces can and do alter CT. As yet there is no sound foundation of research to delineate the range or distribution of manually applied forces. This information is needed in order to compare the basic mechanical testing and clinical techniques, to provide a reliable database for testing the efficacy of these techniques, and to assist in the instruction of students in manual therapy.

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