

Tissue Tolerances of the Muscle-Tendon Unit

Independent Study
Course 30.2.1

Dhinu J. Jayaseelan, DPT, OCS, FAAOMPT
The George Washington University
Washington, DC

CONTINUING PHYSICAL THERAPY EDUCATION



Tissue Tolerances of the Muscle-Tendon Unit

Christopher Hughes, PT, PhD, OCS, CSCS—Editor

Cover Illustration by Joseph Kinstler

Dear Colleague,

I am pleased to introduce the monograph, *Tissue Tolerances of the Muscle-Tendon Unit* by Dr. Dhinu J. Jayaseelan, DPT, OCS, FAAO-MPT. This work is part of the Academy of Orthopaedic Physical Therapy Independent Study Course's series titled: 30.2, Tissue Tolerances.

Dr. Dhinu Jayaseelan is an Assistant Professor in The George Washington University's Program in Physical Therapy. He received a Bachelor of Science in Exercise Science from James Madison University and his Doctorate in Physical Therapy (DPT) from The George Washington University. He then completed advanced training at the Virginia Orthopedic Manual Physical Therapy Institute (VOMPTI). He also completed a post-professional fellowship at the University of Illinois at Chicago. Dr. Jayaseelan is a Board-Certified Specialist in Orthopaedics (OCS) and is a fellow in the American Academy of Orthopedic Manual Physical Therapists (FAAOMPT). Dr. Jayaseelan began teaching in his content area of expertise soon after graduating with his DPT. At George Washington University, he teaches courses in the management of musculoskeletal dysfunction, basic biomechanics, applied kinesiology and an advanced manual therapy elective. He also serves as co-academic director of the orthopedic residency which is a joint venture between Johns Hopkins Hospital and George Washington University. He also is on faculty with VOMPTI and a senior faculty advisor with the Maitland-Australian Physiotherapy Seminars. Dr. Jayaseelan frequently teaches continuing education courses in orthopedics and manual therapy regionally and nationally. Dr. Jayaseelan's research in orthopedics specifically focuses on the management of tendon dysfunction and patellofemoral pain. He is investigating the use of manual therapy for conditions, the presence and management of sensitization in peripheral health conditions, and the bias in clinical reasoning. He has published numerous peer-reviewed articles, a number of book chapters, and has received awards for his research at national conferences. In addition to performing research, Dr. Jayaseelan serves as a content expert and peer reviewer for a number of orthopedic, sports, and manual therapy journals, and is an Associate Editor for the *Journal of Manual and Manipulative Therapy*.

In the monograph, Dr. Jayaseelan discusses the primary factors that affect the capacity of the muscle/tendon unit to facilitate human movement. The content is clinically focused. Anatomy topics include skeletal and tendon tissue and also the myotendinous junction. Biomechanical concepts of the normal tissue are applied to force generation, loading, and the stretch-shortening cycle. Clinical topics of muscle/tendon mobility are discussed in regard to muscle performance, functional movements, and patient self-reported functional outcome measures. A separate section on pathologic changes with disease or injury details the risk factors and mechanisms underlying muscle and tendon Injury. Aging, immobilization and/or disuse, co-morbidities as well as pharmacologic agents are highlighted. A nice section on diagnostic evaluation tools follows. Physical therapy management specifically addresses exercise and manual therapy. The impact of modalities on recovery is also included. Medical management through injections, shockwave therapy, tendon needling, and surgical intervention are informative. A concluding section on developing tissue tolerance and adaptation relates to injury prevention strategies.

An evidenced-based approach is taken to present contemporary physical therapy and medical management of the pathologic muscle/tendon unit. Clinical reasoning forms the basis of the interventions selected as well. Four case studies also assist in applying the knowledge to clinical practice. Management priorities are detailed to guide the reader through patient presentations similar to those routinely encountered in the clinic. The cases specifically cover (1) postoperative shoulder pain and functional loss, (2) chronic elbow pain, (3) acute thigh injury, and (4) recurrent anterior knee pain.

Dr. Jayaseelan accurately reminds us that impairment to the muscle-tendon unit and subsequent alteration in force production and voluntary movement can contribute to substantial disability. Only through a detailed understanding of the muscle/tendon unit can clinicians accurately identify root cause and optimizing movement dysfunction to return patients to their prior level of function and reduce risk of reinjury. Clinicians, researchers, educators, and students working in an orthopedic or sports setting will find the material practical and readily able to be applied to patient care. I am most appreciative to Dr. Jayaseelan for taking the time to add this topic to our series on Tissue Tolerances.

Sincerely,

A handwritten signature in black ink, appearing to read "Chris Hughes".

Christopher Hughes, PT, PhD, OCS, CSCS
Editor

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Tissue Tolerances of the Muscle-Tendon Unit

Dhinu J. Jayaseelan, DPT, OCS, FAAOMPT
The George Washington University
Washington, DC

ABSTRACT

CONTENT: This monograph discusses the wide ranging variables that affect the capacity of the muscle-tendon unit to facilitate human movement. A spectrum of clinically relevant content is covered, from anatomy and biomechanical considerations of normal tissue to pathologic changes with disease or injury. Current evidence regarding contemporary physical therapy and medical management of the pathologic muscle-tendon unit is presented and evaluated. Clinical reasoning related to intervention selection is also discussed. This content is intended to be useful for clinicians, researchers, educators, students, and all other stakeholders in orthopedic and sports settings. **CASE ANALYSES:** Four case studies are presented to assist in the application of knowledge in clinical practice. Specific tissue tolerance considerations are highlighted and management priorities are detailed to guide the reader through patient presentations similar to those encountered every day in the clinical setting.

Key Words: capacity, musculotendinous injury, tendinopathy

LEARNING OBJECTIVES

Upon completion of this monograph, the course participant will be able to:

1. Understand clinically relevant normal muscle and tendon tissue anatomy and biomechanics.
2. Understand physiological mechanisms and processes associated with pathologic muscle and tendon tissue.
3. Describe clinical and diagnostic tools used in identifying muscle-tendon abnormality.
4. Discuss the evidence surrounding the physical therapy management of dysfunctional muscle-tendon units.
5. Discuss the evidence related to medical and alternative management of the dysfunctional muscle-tendon unit.
6. Cite evidence related to improving muscle-tendon tissue tolerance to load, including injury prevention strategies.
7. Apply acquired information to case-based patient scenarios to enhance understanding and clinical reasoning in physical therapy management of muscle-tendon pathology.

INTRODUCTION

Human motion is a smooth coordinated process requiring a series of complex interactions of numerous body systems. An intricate relationship between muscles, tendons, and bones, and the seamless way that tissues work together so coherently allow us to perform our functional, recreational, and sport-related

activities. When any part of the neuromusculoskeletal system becomes dysfunctional, clinicians are tasked with identifying and optimizing movement dysfunction to return the patient/client/athlete to their prior level of function. In order to identify dysfunction rapidly and effectively, it is imperative that we understand how typical movement occurs.

We could not have normal movement without a functional muscle and tendon unit. When a muscle contracts, it creates pull on the tendon that anchors the muscle to a bone, allowing the bone to move as needed for a task. Impairment to the muscle-tendon unit (MTU, for the purposes of this monograph) and subsequent alteration in force production and voluntary movement can contribute to substantial disability. In 2016, the Global Burden of Disease study reported that between 20% and 33% of people across the globe live with a painful musculoskeletal condition.¹ In the United States, that number is as high as 1 in 2 adults, contributing (with indirect costs) to an economic burden of \$874 billion in 2015, or 5.7% of the gross domestic product.² While these data are not specific to MTU pathology, musculoskeletal disorders typically are accompanied by alterations in movement, which is commonly associated with MTU impairment. Therefore, it is essential for clinicians, researchers, students, and all other orthopedic and sports medicine stakeholders to understand the tissue tolerances of muscles and tendons, so they can evaluate and treat MTU dysfunction effectively.

The purpose of this monograph is to describe normal MTU architecture and function, pathologic MTU, and clinical management options for treating MTU dysfunction.

NORMAL MUSCLE-TENDON UNIT

Understanding normal muscle and tendon architecture and tissue development can be helpful in optimizing management of dysfunction. This section describes clinically relevant anatomical considerations, biomechanical principles, and clinical methods of measuring tissue capacity with the aim of allowing for more targeted treatment and enhancement.

Anatomy

Skeletal muscle tissue

Muscle is abundant in the human body, and can be responsible for up to 50% of our total body weight.³ Skeletal muscle allows the human body to achieve and sustain positioning and movement. During any functional activity, muscles shorten, elongate, or maintain activity without changing length, in order to ensure efficient, safe, and appropriate task performance. To understand normal muscle activity and capacity, it may be helpful to first review basic muscle structure.

Skeletal muscle architecture is intricate.⁴ Contractile proteins, actin and myosin, and noncontractile proteins such as titin and desmin combine to create myofilaments. Many myofilaments combine to create myofibrils. A group of myofibrils create a muscle fiber, the structural unit of a muscle, which is surrounded by a thin layer of connective tissue called the endo-

mysium. Numerous muscle fibers, grouped together in a parallel alignment, form a muscle fascicle, which is surrounded by a thicker connective tissue called perimysium. Finally, a muscle belly (readily observed on visual observation during cadaver dissection) is a collection of muscle fascicles, and is surrounded by an epimysium. The endo, peri, and epimysiums enhance structural organization and improve mobility against surrounding structures. The hierarchical structure is shown in Figure 1.1.

While the muscle fiber is the structural unit of a muscle, its shortening and elongation is dependent on sarcomeres, which are components of the myofibril. Each sarcomere consists of the previously mentioned contractile and non-contractile proteins. Sarcomeres are serially organized with overlapping thin (actin) and thick (myosin) filaments contributing to a banded appearance on histopathological examination.

Vascular supply to skeletal muscle is essential to performance, because tissue oxygenation is needed for various repetitive activities such as gait or exercise. The presence of a functioning vascular supply also enhances the capacity of a muscle tissue to heal and recover from injury, unlike in other types of tissue, such as collagenous tissue. Primary arteries provide vascular inflow to skeletal muscles, and penetrate the epimysium and perimysium through feed arteries and branching arterioles to reach the muscle fibers. Capillaries surround each muscle fiber in a sweeping non-uniform and variable distribution.⁵ Veins

and venules are arranged in a similar fashion to arteries and arterioles.

Innervation of skeletal muscle comes from branches of peripheral nerves. A motor unit consists of a single motor neuron and all of its innervated muscle fibers. Muscles that require fine motor skills, such as those in the hand, have a smaller number of muscle fibers per motor neuron. Larger muscles responsible for gross movement, such as the quadriceps, have more muscle fibers per motor neuron.

Tendon tissue

Tendons perform the important task of transmitting tensile load from muscle to bone, providing joint movement and stability. Dense connective tissue allows tendons to absorb and transmit substantial loads without rupture. Cellular material makes up about 20% of tendons, and the extracellular matrix (ECM) accounts for about 80% of the total tissue volume. The ECM is 55% to 70% water. The remaining percentage of the ECM is primarily solids: mostly collagen, but also proteoglycans, elastin, and other proteins.⁶

Tenocytes are the cells primarily responsible for tendon metabolism. Arranged in parallel alignment along the line of stress, tenocytes balance the production and destruction of the ECM. The ECM's water content, collagenous tissue, and additional proteins contribute to the structure and adaptation to mechanical loading. The collagenous tissue contributes to the

considerable ability of a tendon to withstand large tensile forces while elastin allows for some mechanical deformation and compliance, to avoid disruption. Collagen type I is the predominant fiber type in tendons, and is synthesized in response to mechanical loading by tenocyte activity. The structural hierarchy of a tendon (from smallest to largest unit) begins with collagen molecules, which aggregate in a heads (positive charge) to tails (negative charge) alignment to create a microfibril. A collection of microfibrils creates a fibril. A combination of fibrils creates a bundle, which is surrounded by an endotenon. A tendon is a combination of bundles (Figure 1.2). The epitendon, a loose connective tissue, surrounds the collection of bundles and transmits lymphatics, blood vessels, and neural tissue to the tendon. The densely packed and parallel aligned tissues contribute to the mechanical stability, primarily in response to tensile loading.

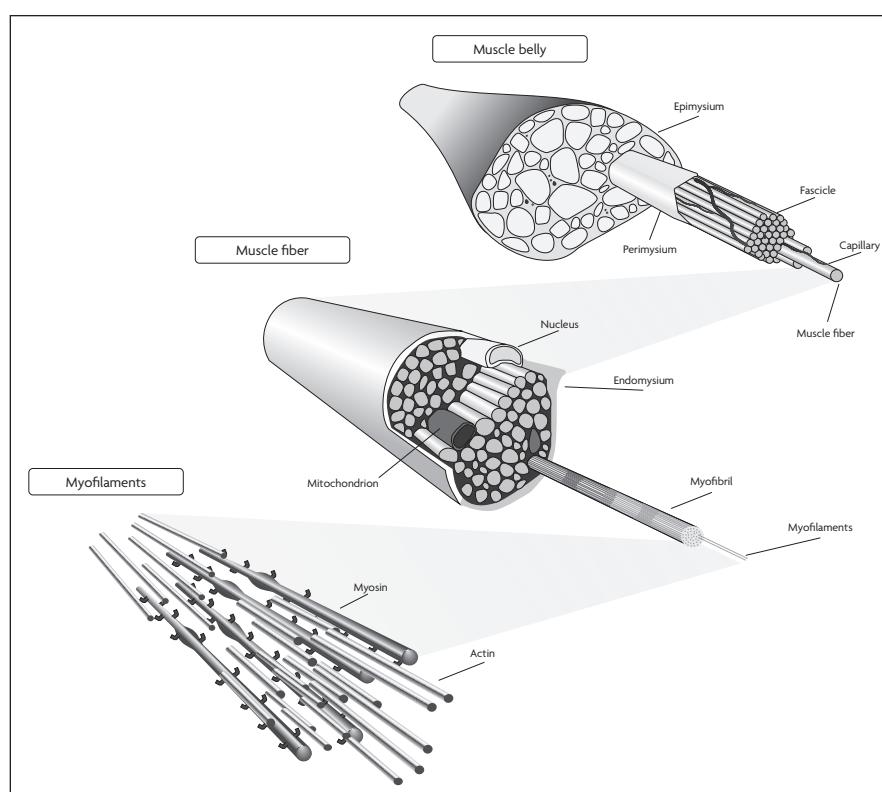


Figure 1.1. Skeletal muscle architecture.

The vascular supply of tendons is vital in maintaining healthy tissue, and has significant implications in tissue injury and repair. During cadaveric observation, tendon tissue is a shiny white color, as compared to muscle tissue which is red. This is because tendon tissue has a limited vascular supply; blood vessels represent only 1% to 2% of the ECM.⁶

Tendon vascular nutrition is supplied by blood vessels from the perimysium, periosteal insertion, and paratenon or tendon sheath. Within the tendon sheath, synovial fluid flushes the tendon providing lubrication and enhanced gliding. The amount of blood supply depends on a number of factors, such as anatomical location, morphology, previous injury, and activity levels.⁷ Neural innervation is limited, but is provided by small branches of nerve fibers that penetrate the epitenon, rarely terminating within the tendon itself.

Myotendinous junction

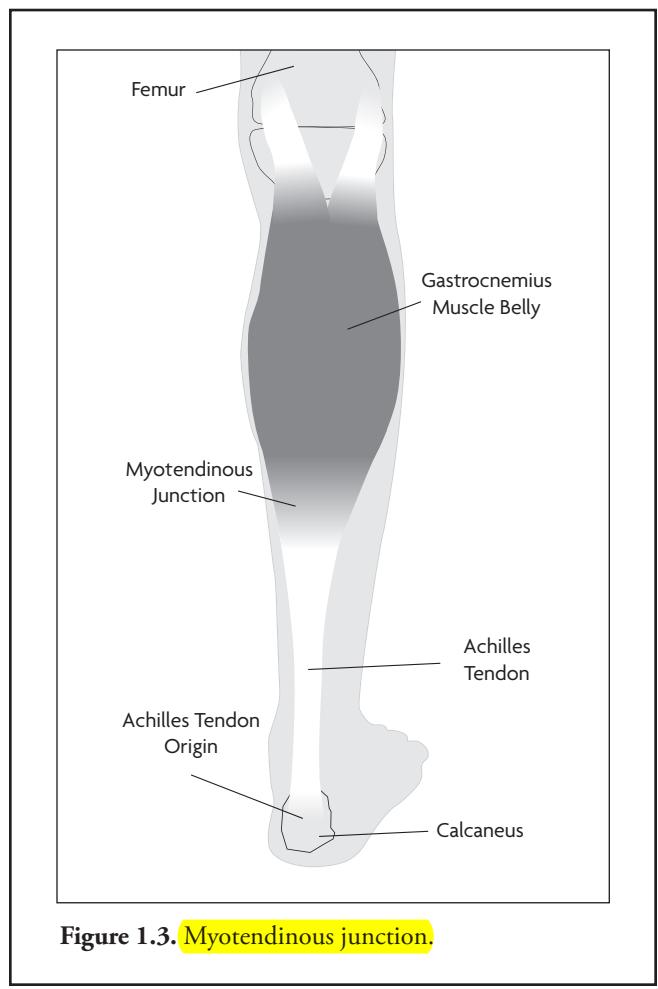
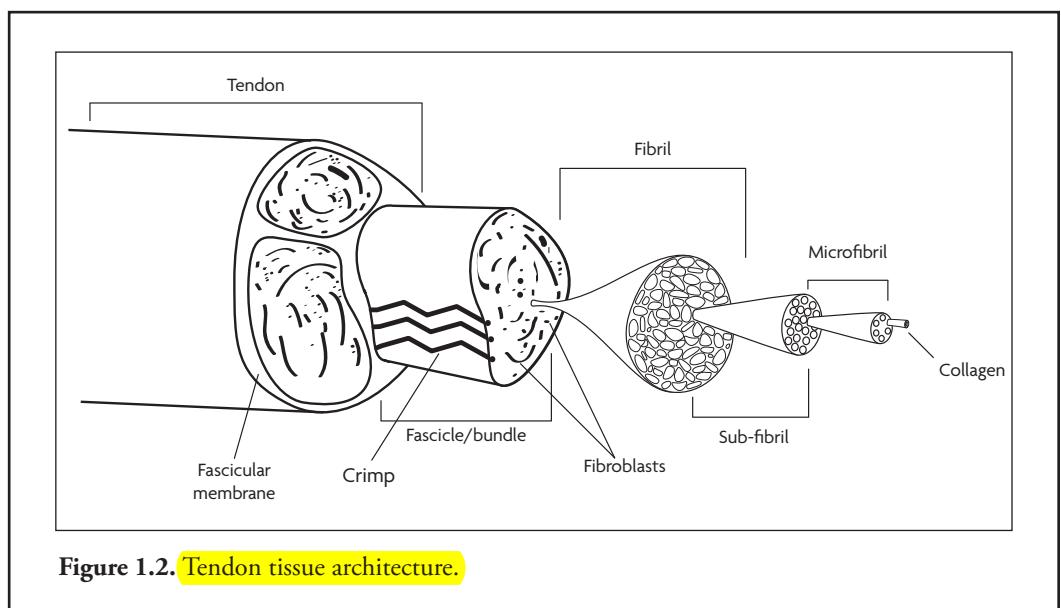
The myotendinous or musculotendinous junction (MTJ) is where skeletal muscle and collagenous tendon tissue meet to create an MTU (Figure 1.3). The MTJ potentially can be a failure point in injury because of the high amount of stress that is transmitted from the tendon to the muscle and the muscle to the tendon. Because of its specialized purpose, the MTJ anatomy is unique. Generally, tendon tissue is oriented longitudinally to allow a uniform directional force transmission. At the MTJ, collagenous projections of the terminal tendon appear to be multidirectional in nature. Similarly, rather than a smooth orientation, a 3D analysis study of the MTJ found that collagen fibrils appear ridge-like and muscles furrow-like, with myofilaments terminating in the ridge-like protrusions.⁸ The increased contact area at the MTJ almost creates a locking mechanism, making the muscle-tendon interface inherently stronger to meet the demands of movement.

Biomechanical Considerations of the Muscle-Tendon Unit

Force production in muscle

The physiology of a muscular contraction is complex.⁹ A number of factors play a role in the ability of a muscle to contract, relax, and perform the requisite force production for a given task. For example, the physiologic cross-sectional area

(CSA) and pennation angle of a muscle affect the amount of force that can be transmitted through the tendon to the bone.¹⁰ The larger the CSA of a muscle, the greater the capability of a muscle to generate force. Pennation angle describes the orientation between the muscle fibers and the tendon. Generally,



pennated muscles can create greater force than fusiform muscles with similar volume.¹⁰

A key relationship in muscle force capacity is the length-tension relationship (Figure 1.4). Force production is linked to active and passive tension of a muscle. Muscles tend to generate the most active force when in a mid-range position. When muscles are shortened or elongated from neutral, alterations in actin-myosin overlap at the sarcomere are thought to reduce the creation of active tension. With elongation, particularly of two joint muscles, active tension may decrease, yet passive tension of the muscle actually increases, to create a greater total tension than when in mid-range or shortened positions.¹⁰ This may help explain why eccentric muscle contractions allow control of greater loads.

The load-velocity relationship is another concept in muscle activity. There appears to be an inverse relationship between the external load applied and the speed of shortening of a concentrically contracting muscle. This makes sound clinical sense, as we expect patients will be able to perform a task more rapidly when they have less resistance. If an external load equals the maximal force a muscle can apply, there will be no movement, and the muscle will be working isometrically. When the load increases beyond force exertion, the muscle will elongate, or eccentrically contract. The muscle will elongate faster as the load is increased. This will be important to consider when determining the amount of load and resistance needed to assure safe task performance.

The force-time relationship suggests that as the time of contraction increases, so will the amount of force generated. Slower muscle contractions may allow appropriate contractile protein positioning, in turn enhancing the capacity to reach maximal tension. This is relevant to clinicians creating rehabilitation programs. For a patient recovering from a hamstring strain who is attempting to improve muscle performance impairments, performing knee flexion rapidly against minimal resistance will not develop as much strength as performing more controlled contractions.

Power affects the speed at which tasks are performed. Power is defined as the rate of work (force x distance) performed

over time, and is usually described in units of joules. When a task is performed in a shorter duration of time, more power can be generated. Plyometric and sport tasks are often considered to be powerful movements, yet slow movements also can require significant power. For example, even if performed at a slower speed, exerting force over a large distance can create substantial work. The role of power can be essential in the rehabilitation or training of the patient/athlete, to allow a given MTU to develop appropriate capacity to complete a given task.

Muscle fatigue is an additional concept to consider in understanding force production. In contrast to the fatigue we see in clinical settings, muscular fatigue is defined as an exercise-induced reduction in the ability of muscle to produce force or power.¹¹ A wide variety of mechanisms have been hypothesized for the development of fatigue, including reduced excitability at the neuromuscular junction or sarcolemma, changes in excitation-contraction coupling, alterations in contractile mechanics, reduced blood flow or oxygenation supply.¹⁰ Whether involved muscles are primarily slow-twitch (Type I aerobic) or fast-twitch (Type IIx anaerobic or IIa mixed), when the muscle is no longer able to meet the demands of a task, performance will decline.

Tendon tolerance to tensile load

Basic science studies allow researchers to investigate the mechanical properties of tissues in a number of different environments. The parallel orientation of tendon and longitudinal alignment from the bone to muscle interface suggests a primary ability to tolerate tensile load. By creating and plotting load elongation or stress-strain curves, various physiological properties of tendon tissue can be elucidated. Understanding the design principles and purpose of various biomechanical concepts serves numerous purposes. For example, extrapolation can produce essential clinical data in the design of plans of care.

A load elongation curve provides information regarding a tendon's capacity to tolerate tensile force, through loading the tendon to failure. On a load elongation curve plot, the x-axis represents the amount of elongation or deformation, while the y-axis represents the amount of load or force applied (Figure 1.5). The slope of the graph identifies the stiffness of the tissue, and the point at which continued elongation is coupled with a downslope is considered the tissue failure point. These curves can provide quantitative data regarding the ultimate load and elongation allowed prior to failure, as well as the total energy the tissue was able to absorb (the area under the curve).¹²

Similar to load elongation curves, stress-strain curves measure the capacity of a tissue under tensile load. Rather than elongation being a discrete measure of distance, strain (x-axis) is considered the tissue's percentage of elongation. The y-axis, or stress, is the load per unit of area. The slope of the stress-strain curve reveals the tendon's modulus of elasticity. In the majority of human tendons, the modulus of elasticity is linear, and increased loads create greater elongation. This is relevant for the

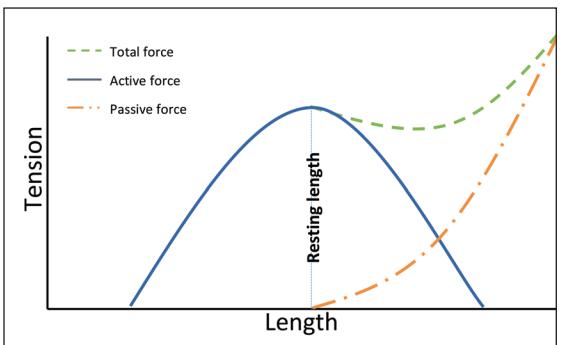


Figure 1.4. Length-tension relationship.

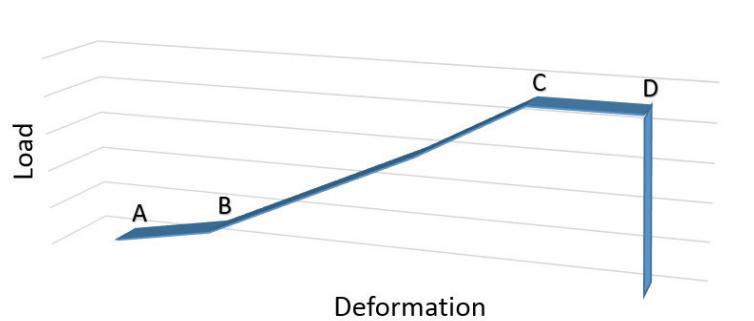


Figure Key. A – initiation of deformation; B – end of toe region, beginning of linear region; C – yield point; D – failure point, disruption of the tendon occurs. A to B – this period tensions the inherent tendon crimp, straightening out wavy collagen fibers; B to C – the slope of this linear period is described as the stiffness of the tissue; C to D – continued deformation occurs despite constant load, irreversible changes are made to the tendon tensile strength; Area under the curve – total amount of energy absorbed by the tissue

Figure 1.5. Load elongation curve.

orthopedic and sports clinician, in understanding how to stress a healing tissue without reaching the failure point.

While tendons can tolerate substantial tensile loading, compressive and torsional forces are not as well accepted. Compression, friction, and shearing of the tendon is frequently seen at the tendon's bony insertion. Care should be taken to consider appropriate and inappropriate forces applied (exposed) to the tendon during rehabilitation and performance enhancement programs.

Stretch-shortening cycle

While muscle function and human movement are often described in terms of isometric, concentric, and eccentric contractions, the human body actually uses stored energy and momentum to accomplish many functional repetitive movements. The stretch-shortening cycle (SSC) is a natural type of muscle function derived from the combination of eccentric lengthening and concentric shortening of muscles, to enhance the efficiency and performance of movement. The SSC is typically rapid and is integrated somewhat seamlessly into movement, yet it relies on a sequence of complex tissue interactions with mechanical, metabolic, and neural elements of involvement.¹³

Generally, an SSC occurs in two main conditions: (1) pre-activation and (2) variable activation of muscles preceding the functional movement.¹⁴ The SSC is incorporated in activities involving both the upper and lower extremities. Jumping is a good example. Just before landing from a jump, the individual will have preparatory muscle activity to resist impact (pre-activation), followed by an active braking phase, stretching, and then immediate shortening of various lower extremity muscles such as the gastrocnemius muscle to propel the individual back off the ground (variable task specific muscle activation). Similar to compressing a spring and letting it recoil and jump off your

hand, the MTU serves as a spring for the human body, using elastic strain energy storage to subsequently move the body part. It should be noted, however, that the overall MTU elongation is relatively small, somewhere in the range of 6% to 8% of the muscle-tendon length.¹⁴ While the elastin and viscoelasticity of the tendon allow for some compliance and passive elongation, the relative MTU stiffness is important and necessary to avoid a loss of reflexive propulsion.

Clinical Methods of Identifying Tissue Tolerance and Capacity

A wide array of factors contribute to a person's capacity to perform normal movement. Some factors are modifiable while others are not. To estimate an individual's capacity to perform a task, clinicians should start by assessing the baseline function (or lack thereof) of the MTU. This should be completed at multiple levels of the International Classification of Functioning, Disability and Health model, the body functions and structure, activity and participation levels.

Muscle-tendon mobility

As noted previously, muscles can provide greater active force in mid-range positions, while passive tension increases with lengthening. It stands to reason that if a muscle is adaptively shortened, the muscle's passive and resultant total tension capacity would be limited, although conflicting evidence surrounds mobility impairments as a risk factor for injury.¹⁵ If a muscle or joint system has mobility restrictions, tasks can still be functionally completed, but likely with compensation. Therefore, to estimate a MTU's capacity to generate and accept force, the MTU's mobility should be assessed, particularly in cases when muscles cross two joints.

In the lower extremity, restrictions are common in the hamstrings, rectus femoris muscle, and gastrocnemius muscle. These muscles crossing two joints consistently complete the SSC during daily activities and sports. To assess if the muscles can accommodate frequent fluctuations of position and load demands, therapists can use clinical tests to evaluate the length of the tissues, such as the Thomas test for the rectus femoris muscle (Figure 1.6). In tensioning two joint muscles, therapists should also consider the impact on mobility of additional tissues, such as the nerves. For example, to assess the functional mobility of the hamstrings in a patient with proximal hamstring tendinopathy ("opathy" is a suffix used to denote disease, derived from the Greek *pathos* or suffering), the clinician performs a straight leg raise (Figure 1.7). When the clinician reaches tissue resistance, the patient complains of posterior thigh tightness,



Figure 1.6. Thomas test to evaluate rectus femoris length.



Figure 1.7. Straight leg raise to evaluate hamstring length.

changes of the proximal hamstring may create a tethering of the sciatic nerve, increasing the risk of nerve mobility restrictions. Particularly with muscular or tendinopathic changes adjacent to nervous tissue, clinicians should consider what a muscle length assessment is really evaluating.

Limitations in muscle length will prevent a joint from moving through its available range. Similarly, restrictions in joint accessory motion will limit the quantity of osteokinematic movement. Using the shoulder as an example, consider what may happen if the glenohumeral joint is stiff. When reaching the arm overhead, the humerus needs to roll, spin and slide within the glenoid fossa to avoid subacromial impingement. If the humerus is unable to move the requisite amount due to joint or capsular restriction, the likelihood increases of impingement of the rotator cuff or the long head of the biceps tendon. Furthermore, reduced joint mobility was found to negatively affect sarcomere length and collagen fibril alignment in a rat.¹⁶ Assessment of joint motion is typically done in the open-packed position to avoid confounding variables of restriction. The question of which came first, the muscle problem or the joint restriction, is challenging to answer, but by prioritizing one problem, the clinician will likely have an impact on both tissues.

Muscle performance

In addition to examining a MTU's mobility, measuring force production can help to identify areas of weakness or need for enhancement. A classic method of clinically objectifying muscle strength is manual muscle testing (MMT). Manual muscle testing is assessed for various muscle groups by having the person sustain a position (typically midrange) against gradually progressive resistance from the examiner, for up to 5 to 6 seconds. While intra-rater and inter-rater reliability of MMT varies depending on the muscles tested, kappa values can range from poor to excellent.¹⁷ One possible reason for the variable reliability is the lack of precision with the 0 to 5 MMT grading scale. To improve this, a hand-held dynamometer (HHD) can quantify muscle force production with greater detail, often reported in pounds. One challenge to widespread clinical use of HHD is the cost of the equipment, which can be upward of \$1,000 per unit.

Manual muscle testing using either traditional grading or HHD can provide substantial information on the ability of a muscle to produce and sustain force. However, during functional tasks, the MTU typically is expected to be active and passive in a repetitive fashion, thus, a single result of MMT may be normal but not relevant. With this in mind, clinicians may want to perform a series of MMT repetitions of a muscle or muscle group, to determine the MTU's capacity to create and sustain force over time. Or, if a muscle is expected to be isometrically active for greater than 5 to 6 seconds, clinicians can hold resistance for extended durations to more closely replicate the needed force generation.

with some tingling. In this position, the clinician is tensioning the hamstrings from their origin at the ischial tuberosity to their insertion sites distal to the knee joint, but he or she may also be 'tensioning' the sciatic nerve. Specifically with proximal hamstring tendinopathy, scar tissue development and tendinopathic

Dynamic/functional movements

While muscle force production in standardized static positions can help to develop a baseline and metric to determine change and progress, single isometric holds do not necessarily correlate to the potential or the ability to perform functional tasks. Additional limitations may exist with MMT, such as a lack of sensitivity, results dependent on the tester's strength, and a possible ceiling effect. As a result, additional tests may be necessary to accurately identify a person's muscle function, in turn evaluating their MTU ability.

To illustrate the point, consider the testing of the quadriceps muscles for a patient with patellar tendinopathy. To assess the patient's quadriceps muscle force output, the therapist performs MMT (in a nonweight bearing seated position – which is often not provocative for the condition). Resisted knee extension may be strong and painfree, causing strength to be considered normal, despite the person having a pathological MTU. A functional sit to stand can be performed as it has been shown to better detect weakness of the quadriceps, suggesting greater diagnostic sensitivity.¹⁸ A declined single leg squat (Figure 1.8) and hop testing may also be relevant for this patient, to increase the eccentric load on the quads, tensile strain on the patellar tendon, and to use the various load and time relationships to stress the MTU at different rates. Dynamic testing may also represent more accurately the functional demand placed on a MTU. The MMT for the gastrocnemius muscle (and its Achil-

les tendon) is repeated single-limb heel raises. While repeated ankle plantar flexion is a requisite during gait, hop testing may more accurately test the capacity of the plantar flexor complex, given the need for power and push off beyond active range of motion (ROM).

Although less readily available in some clinical settings compared to research-based settings, isokinetic testing can be useful in evaluating muscle capacity and predicting functional ability. Isokinetic muscle testing is performed with a constant speed of angular motion with variable resistance. Concentric and eccentric muscle activity can be captured to more closely mimic the functional demand, such as that required by the rotator cuff in overhead sports. An additional benefit is the possible predictive nature of data gathered from isokinetic strength testing. In the anterior cruciate ligament (ACL) literature for example, the quadriceps muscle's peak torque as measured by isokinetic testing demonstrated a statistically significant positive correlation to hop test performance,¹⁹ which is often clinically used in return-to-sport decision making.

There are numerous systematic approaches to analyzing movement and identifying dysfunctional movement. Regardless of the approach used, clinicians should assess the various types of MTU function in some fashion, in an effort to understand the patient's or athlete's baseline MTU tolerance to load. Dynamic and functional activities evaluate the role and possible tolerance of the specific MTU for a given task, and have the added benefit of putting the MTU into the context of the individual's upper and lower extremity function. Specifically integrating static and dynamic assessments of muscle performance can allow the clinician to make appropriate decisions on progression and regression, depending on the MTU tissue tolerance.

Patient self-reported functional outcome measures

Although it is important for the clinician to assess the physical capacity of the MTU, the self-reported activity and participation restrictions can provide essential insight into the patient's perceived ability, or inability, to perform various tasks. It is important to quantify the patient's reported disability through validated outcome measures at baseline to identify change with intervention. These tools can also be more specific, appropriate, and relevant compared to various pain scales or Likert scales for patient-specific education and identifying improvement. Integrating self-reported outcome measures allows clinicians to use the biopsychosocial approach to patient management rather than the biomedical model. Validated outcome measures also assist in justifying the need for services to third-party payers.

Rarely is a patient-reported outcome (PRO) measure specific to a single muscle, given the numerous muscles that could be injured or dysfunctional (let alone the inherent limitations of research designs to use such specific tools). To capture more patients and improve tool functionality, body region or pathol-



Figure 1.8. Single leg decline squat.

ogy-specific PROs are often used in clinical practice to identify level of disability and serve as a baseline for change. For example, rather than using a PRO for a triceps brachii muscle short head tear (which likely does not exist), more general shoulder outcomes such as those identified on the Disability of the Arm, Shoulder and Hand questionnaire would be relevant to identify the current level of function. Another option is the PRO that was developed to describe the impact of sarcopenia, which may be of use for persons with generalized weakness related to aging or deconditioning.²⁰

A number of PRO measures can quantify the level of activity and participation restrictions for persons with tendon-related pain. The Victorian Institute of Sport Assessment created pathology specific questionnaires for Achilles, patellar and proximal hamstring tendinopathies as well as greater trochanteric

pain syndrome (which often includes gluteal tendinopathy). These outcome measures have demonstrated validity, reliability, and some have cross-cultural adaptations. Commonly used PROs for persons with MTU dysfunction, including relevant patient populations and psychometric properties, can be seen in Table 1.1. This table is not exhaustive, but offers a starting point for identifying applicable tools for MTU tissue intolerance.

PATHOLOGIC MUSCLE-TENDON UNITS

Understanding normal MTU anatomy, development and biomechanics can be helpful in identifying and treating dysfunction. Incorporating biomechanical principles of muscle and tendon function can safely, effectively, and efficiently enhance the quality of rehabilitation of pathologic MTUs. Beyond the

Table 1.1. Patient Self-reported Outcome Measures Used to Evaluate MTU Dysfunction

Outcome measure	Populations/conditions examined	Tool properties	Psychometric utility
Commonly used body region specific PROs			
Disabilities of the Arm, Shoulder and Hand (DASH) ²⁰	Wrist, hand and shoulder pathology	- 30 questions - Each question rated 1-5 - Higher scores indicate greater levels of disability	- MCID: 10.2 points - Excellent test-retest reliability (ICC = 0.96)
QuickDASH ²¹	Patients with shoulder pain	- 11 questions - Total score 0-100 - Higher scores indicate greater levels of disability	- MCID: 8 points - MDC: 11.2 points - Test-retest reliability (ICC = 0.90)
American Shoulder and Elbow Surgeons (ASES) shoulder score ²²	Various shoulder pathologies	- 11 questions (1 pain, 10 function) - Total score 0-100 - Higher scores indicate greater levels of function	- MCID: 6.4 points - MDC: 16 points - Excellent test-retest reliability (ICC = 0.84) - Acceptable internal consistency (Cronbach α = 0.86) - Good construct and discriminative validity
Lower Extremity Functional Scale (LEFS) ²³	LE musculoskeletal conditions (joint, muscle or soft tissue of the LE)	- 20 questions - Each question rated 0-4 - Total score 0-80 - Higher scores indicate greater levels of function	- MCID: 9 points - MDC: 9 points - Excellent test-retest reliability (r = 0.94) - Good construct validity (r = 0.80)
Foot and Ankle Ability Measure (FAAM) ²⁴	Broad range of musculoskeletal disorders of the lower leg, foot and ankle	- 29 total questions (21 ADL subscale, 8 sports subscale) - Total score 0-100 - Higher scores indicate greater levels of function	- MCID: 8 or 9 points (ADL and sports subscales, respectively) - Good test-retest reliability for ADL (r = 0.89) and sports (r = 0.87) subscales

Table 1.1. Continued

Outcome measure	Populations/conditions examined	Tool properties	Psychometric utility
General muscle loss PRO			
Age-related muscle loss questionnaire ¹⁹	Adults with sarcopenia	<ul style="list-style-type: none"> - 14 questions - Each question rated 0-10 - Higher scores indicate greater levels of difficulty 	<ul style="list-style-type: none"> - Not yet established to date
Commonly used PROs for tendinopathic conditions			
VISA-A ²⁵	Achilles tendinopathy	<ul style="list-style-type: none"> - 8 questions (3 pain, 3 function, 2 activity) - Total score 0-100 - Higher scores indicate greater levels of function 	<ul style="list-style-type: none"> - MCID: 16 points - Significant construct validity (Spearman's $r = 0.58$) - Strong test-retest ($r = 0.93$), intratester ($r = 0.90$) and intertester ($r = 0.90$) reliability
VISA-P ^{26,27}	Patellar tendinopathy	<ul style="list-style-type: none"> - 8 questions - Total score 0-100 - Higher scores indicate greater levels of function 	<ul style="list-style-type: none"> - MCID: 14 points - Excellent test-retest and inter-tester reliability ($r > 0.95$)
VISA-G ²⁸	Greater trochanteric pain syndrome	<ul style="list-style-type: none"> - 8 questions - Total score 0-100 - Higher scores indicate greater levels of function 	<ul style="list-style-type: none"> - High test-retest intrarater reliability ($ICC = 0.827$) - Face, construct and content validity
VISA-H ²⁹	Proximal hamstring tendinopathy	<ul style="list-style-type: none"> - 8 questions (3 pain, 3 function, 2 activity) - Total score 0-100 - Higher scores indicate greater levels of function 	<ul style="list-style-type: none"> - MCID: 22 points - Test-retest reliability ($ICC = 0.90-0.95$) - Excellent internal consistency (Cronbach $\alpha = 0.84$)
Patient Rated Tennis Elbow Evaluation (PRTEE) ³⁰	Lateral epicondylalgia	<ul style="list-style-type: none"> - 15 questions (5 pain 10 functional activities) - Each question rated 0-10 - Total score 0-100 - Higher scores indicate greater self-reported disability 	<ul style="list-style-type: none"> - MCID: 11 scale points or 37% - Excellent test-retest reliability ($ICC = 0.89-0.96$) - Excellent internal consistency (0.85-0.94)

Abbreviations: ADL, activities of daily living; ICC, intraclass correlation coefficient; LE, lower extremity; MCID, minimal clinically important difference; MDC, minimal detectable change; PRO, patient-reported outcome; VISA, Victorian Institute of Sport Assessment

MTU itself, numerous factors must be incorporated when considering tissue tolerance, predisposing factors to injury, methods of injury, and recovery.

Risk Factors for Muscle and Tendon Injury

Risk factors are commonly categorized as being either extrinsic (those acting from externally on the body) or intrinsic (those acting from within the body). Some common threads

and principles apply but the body region of interest and population studied will affect the likelihood of injury. Being able to identify those who are at greater risk for developing a muscle or tendon injury can potentially enhance the clinician's ability to specifically address impairments at the body structure functions (BSF) level, to minimize the possibility of developing the condition. Among the many intrinsic and extrinsic factors, some can be modified but some cannot.

Extrinsic risk factors for developing a muscle or tendon injury often relate to loading parameters. Excessive loading, training errors, improper equipment, and environmental elements appear to be consistent factors for both upper and lower extremity MTUs. Specifically for patients or athletes with fewer external pressures (eg, not in-season or competing for scholarships), the clinician should be able to modify many of the extrinsic risk factors by changing the training frequency, intensity, time of day, shoewear, etc.

Intrinsic risk factors generally are linked to impairments along the biomechanical chain or to systemic factors. Examples of biomechanical factors include muscle imbalances, muscle and joint mobility restrictions, limb dominance, and leg-length discrepancy.^{32,33} Obesity, hypertension, hyperlipidemia, and diabetes are common medical conditions associated with tendinopathy.^{33,34} Additionally, a history of smoking may predispose individuals to develop tendinopathy.³⁵ Increasing age and history of previous injury may be risk factors for developing muscle injuries.³⁶⁻³⁸ While advancing age and history of previous injuries cannot be modified, many mobility and movement coordination impairments can be improved with exercise, while lifestyle and possible pharmacological interventions can effect change in an individual's health status.

Mechanism for Muscle and Tendon Injury

When the demand on the MTU exceeds its capacity or tissue tolerances, injury occurs. Macrotrauma or repetitive microtrauma are the primary modes of injury to the muscle, tendon, or musculotendinous junction. Micro and macrotrauma to the MTU are common, given the demand placed upon the tissues during daily, functional, and sport-related activities. Epidemiological data and typical mechanisms for common injuries can be seen in Table 1.2.

Macrotrauma to a muscle or tendon often occurs during athletic or functional activities that require large force production over a short period of time. The hamstrings, for example, are frequently injured during sprinting activities, such as soccer. Specifically, during the terminal swing phase of running gait, the hamstrings are eccentrically active across two joints, creating substantial total tension over a brief period of time. When the force needed is greater than the available force, muscle injury is more likely to occur. During acute injuries such as noted in this example, patients or athletes will likely report a sharp localized pain that prevents them from continuing their activity. Depending on the severity, the patient may also report hearing or feeling a 'pop'. Some examples of macrotrauma to a muscle or tendon, other than swift overload during movement or exertion, include lacerations, stabblings, or gunshot wounds.

Microtrauma to a muscle or tendon is a frequent cause of injury related to overuse or overload from repetitive submaximal loading. During most repetitive tasks that the human body performs, muscles and tendons fluctuate among various types of contractions. Running, for example, requires frequent an-

kle plantar flexion for efficient forward propulsion. Although much depends on foot strike patterns, the plantar flexor muscles lengthen during load acceptance to eccentrically control the body's return to the ground, while concentric action and shortening is required during the terminal stance to allow push off. If the calcaneus overly everts, contributing without compensation to excessive mid and forefoot pronation, it may cause excessive torsional and compressive strain on the Achilles tendon, which controls force primarily in the sagittal rather than frontal or transverse planes. While one stride may not cause rupture, over a series of thousands of strides, this 'wringing' effect may overload the tendon, which at the insertion is generally avascular. While this biomechanical example related to movement coordination impairments and mobility deficits is common, repetitive microtrauma is often related to the many risk factors previously noted, particularly faulty training programs. Rapid increases in activity without appropriate rest often is the reason individuals complain of muscle and tendon pain.

Muscle

The first step in treating MTU dysfunction is appropriate diagnosis and classification. The recognition and classification of MTU injuries is important to provide appropriate treatment without symptomatic or pathologic exacerbation, and to minimize time away from activities. Diagnostic criteria can vary depending on a number of factors, resulting in possible challenges in inter-professional communication. Below, recognition classification schemes are presented, with the understanding that additional options exist in the literature and in clinical practice.

Injury grading

In recent years, increased efforts have been made not only to create classification systems that accurately and specifically assess the severity of injury, but also to identify possible markers for prognostic determinations. One such grading system is the British Athletics Muscle Injury Classification,⁴⁹ which has demonstrated substantial inter- and intrarater reliability.⁵⁰

The classification system grades muscle injury on a scale of 0 to 4, 4 being the most severe. Briefly, 0 describes muscle pain without evidence of abnormal imaging, grade 1 is a small tear, 2 is a moderate tear, 3 is an extensive tear, and 4 is a complete tear or rupture. Beyond describing the severity of injury, this classification system attempts to localize the lesion using the letters a, b, and c in conjunction with the numeric grade. For this purpose, "a" denotes myofascial injury to the peripheral portion of the muscle, "b" is an injury within the muscle belly, typically at the MTJ, and "c" describes an injury to the tendon. For example, a complete rupture of the tendon would be graded as 4c whereas a moderate tear at the MTJ would be graded as 2b. Common clinical and imaging features for each grade are summarized in Table 1.3. After applying this grading system to athletes with acute hamstring injuries, intratendinous involvement (grade c) was found to be associated with delayed return to sport and higher incidence of reinjury.⁵¹

Table 1.2. Epidemiology and Mechanism of Injury for Common MTU Injuries

Health condition	Epidemiological data	Common mechanism of injury
Achilles tendinopathy ³⁸	- Incidence: 2.35 per 1,000 people	- Overuse condition - Associated with running or jumping sports
Achilles tendon rupture ³⁹	- Incidence: 21.4 per 100,000 person years	- Typically traumatic - Rapidly pushing off forefoot while extending knee (ie, jumping, basketball, sprinting) - May be linked to spontaneous rupture related to medication, autoimmune disorders, other disease processes
Adductor strain ⁴⁰	- Incidence: 19.87 per 100 players/year (professional hockey players)	- Rapid change in direction, primarily frontal plane (ie, ice hockey, soccer, basketball)
Hamstring strain ⁴¹	- Incidence: 3.7 match injuries per 1000 exposure hours (soccer) - Prevalence: 17%	- Running at or near maximal speed - Movements including end range hip flexion and knee extension
Lateral epicondylalgia ⁴²	- Incidence: 3.5 per 1,000	- Overuse condition - Repetitive wrist extension movements (ie, playing tennis)
Patellar tendinopathy ⁴³	- Prevalence: 8.5% (non-elite athletes)	- Overuse condition - Associated with jumping sports (ie, basketball, volleyball)
Quadriceps strain ⁴⁴	- Injury rate: 1.07 per 10,000 athlete exposures (collegiate athletes)	- Eccentric control of knee flexion and hip extension such as sprinting or kicking (ie, soccer, football, rugby)
Rotator cuff tear ^{45,46}	- Incidence: 2.5 per 10,000 patients aged 40–75 years (acute, full-thickness) - Prevalence: 22.1% (asymptomatic tear twice as likely as symptomatic)	- Fall on outstretched hand - Lifting injury - Additional shoulder trauma (ie shoulder dislocation) - Degenerative
Rotator cuff tendinopathy ⁴⁷	- Incidence: 2.9 – 5.5% - Prevalence: 6.7 – 7.4%	- Overuse condition - Repetitive overhead activity (ie, lifting, carrying)

Tendon

Tendon dysfunction classification

A number of systems to classify the spectrum of tendon pathology exist. Historically, it was common to classify tendon-related pain as tendinitis (suggesting inflammation of the tendon). To treat inflammatory conditions, steroidal and non-steroidal anti-inflammatory medications would be appropriate, and these medications were frequently prescribed. However, the diagnosis of tendinitis is often incorrect, due to the absence of true inflammatory markers and mediators in many cases of tendon-related pain. This may result in an inappropriate prescription of unnecessary and possibly harmful medications. In order to appropriately treat tendon-related dysfunction, it is necessary to understand the various presentations of tendon pathology.

The potential inaccuracy in diagnostic labeling has prompted a movement to increase awareness of the spectrum of tendon pathology. In the majority of cases, tendinopathy has become the preferred term to describe tendon-related pain. To diagnose the actual tendon pathology, clinicians would need additional

imaging or histopathological studies. Delineation of the various pathological diagnoses can be seen in the commonly used Bonar's modification of Clancy's classification of tendinopathy (Table 1.4).⁵²

In the absence of additional diagnostic information, clinicians must rely on the patient's presenting signs and symptoms in determining where their patient fits along the tendinopathy spectrum. Specifically, the patient's age, symptom chronicity, and symptom history should be queried for classification. While tendinopathy can correlate with systemic medical conditions (eg, diabetes mellitus or hyperlipidemia), for the purposes of the tendinopathy clinical presentation continuum, only load-induced presentations are considered. As described by Cook and Purdam,⁵³ the load-induced tendinopathy continuum consists of 3 main phases: reactive tendinopathy, tendon dysrepair, and tendon degeneration. Clinical features and imaging considerations for the phases of this model are detailed in Table 1.5. Although structural or imaging features may not change, and individual factors may play a role, load modifica-

Table 1.3. Muscle Injury Diagnostic Classification⁴⁸

Grade of Injury	Diagnostic Subcategory	Common MRI Findings	Common Clinical Findings
0	a	- Normal	- Localized soreness after exercise - Resistive testing typically strong and pain free
	b	- Normal, or generalized variable high signal changes across multiple muscles	- Generalized muscle soreness after exercise
	+N	- Normal	- Possible neural involvement
1 (small)	a	- High signal change in fat suppressed/STIR images - < 10% into the muscle - Length < 5 cm - Absence of substantial fiber disruption - Intermuscular fluid/ hematoma within fascial planes	<ul style="list-style-type: none">- Tenderness to local palpation- Pain with activity but able to play through, possibly for short duration afterwards- Resistive testing usually strong but painful
	b	- High signal change in muscle, usually at MTJ - < 10% into the muscle - Length < 5 cm - Absence of substantial fiber disruption	
2 (moderate)	a	- High signal change evident from periphery of muscle - Involves 10-50% of cross-sectional area - Injury extends 5-15 cm within muscle - Fiber disruption < 5 cm	<ul style="list-style-type: none">- Tenderness to local palpation- Pain limits participation in activity- Resistive testing painful and weak- Possible guarding, preventing full range of motion
	b	- High signal change evident within the muscle or usually at MTJ - Involves 10-50% of cross-sectional area - Injury extends 5-15 cm within muscle - Fiber disruption < 5 cm	
	c	- Injury extends into the tendon - Involvement < 50% of maximal tendon diameter or 5 cm of longitudinal length	
3 (extensive)	a	- High signal change extending into periphery - > 50% cross-sectional area involvement, or > 15 cm in length - Fiber disruption > 5 cm	<ul style="list-style-type: none">- Sudden onset of pain, potentially immediately limiting- Tenderness to palpation- Guarding with passive assessment and functional activities (ie limp with gait)- Resistive testing painful and weak
	b	- High signal change extending into muscle/MTJ - > 50% cross-sectional area involvement, or > 15 cm in length - Fiber disruption > 5 cm	
	c	- Injury to the tendon - Longitudinal length > 5 cm - > 50% of tendon's cross-sectional area, or > 15 cm in length - Loss of tendon margins but integrity largely maintained	
4 (complete)		- Complete tear of the muscle	<ul style="list-style-type: none">- Sudden onset- Immediately unable to continue activity- Resistive testing weak and pain free- Palpable defect is common
	c	- Complete tear of the tendon	

Table 1.4. Histopathological Classification of Tendinopathy⁵¹

Pathological diagnosis	Macroscopic pathology	Histopathological findings
Tendinitis	Symptomatic tendon degeneration with vascular disruption and inflammatory repair response	Similar degenerative findings as seen with tendinosis with superimposed evidence of tear including fibroblastic and myofibroblastic proliferation, hemorrhage, and organizing granulation tissue
Tendinosis	Intratendinous degeneration usually related to aging, repetitive microtrauma, vascular compromise	Collagen disorientation, fiber separation with increase in mucoid ground substance, increased presence of cells and vascular spaces with or without neovascularization and focal areas of necrosis and calcification
Paratenonitis	Inflammation of the paratenon (outermost tendon layer) alone, regardless of the presence of synovial lining	Mucoid degeneration if areolar tissue is seen. A scattered mild and mononuclear infiltrate with or without focal fibrin deposition and fibrinous exudate frequently seen
Paratenonitis with tendinosis	Paratendonitis with associated intratendinous degeneration	Similar degenerative changes as noted with tendinosis with mucoid degeneration with or without fibrosis and scattered inflammatory cells in the paratenon areolar tissues

tion (progression or reduction) is commonly used to increase or alleviate a patient's pain and function.⁵⁴

Pain Considerations

Pain is the most common complaint of persons seeking orthopedic services. The presence of pain may have deleterious effects on the MTU, such as muscle inhibition, movement pattern alterations, and reductions in task performance quality. Pain is an extremely complex concept, and can be challenging to treat for a host of reasons, one being the subjective nature of the problem. In the acute phase of tissue injury, inflammatory mediators contribute to sensitization of various peripheral structures. Acute pain serves a biologically protective role, to avoid progression or worsening of injury. Frequently, after the inflammatory or acute phases of tissue injury are complete, pain persists. Treating BSF impairments can reduce the impact of dysfunctional movement on healing tissues.

Related in part to the challenge of identifying and treating specific tissues responsible for a patient's pain experience, some authors have suggested the need to assess and treat pain mechanisms.^{55,56} When pain is localized, aggravated, or alleviated with predictable activities, and in the absence of paresthesia, as is often the case with muscle and/or tendon dysfunction, the primary pain mechanism is usually considered peripheral nociceptive. Peripheral nociceptive symptoms often respond positively to appropriate tissue loading/unloading through exercise and patient education. Interestingly, despite the peripheral presentation, some muscle and tendon conditions are associated with

central sensitization (CS). For example, shoulder pain,⁵⁷ lateral epicondylalgia,⁵⁸ patellar tendinopathy,⁵⁹ and Achilles tendinopathy⁶⁰ have been linked to altered central pain processing mechanisms, although conflicting evidence exists regarding the lower extremities.^{61,62}

To assess for the presence of sensitized nociceptive pathways and processing mechanisms, clinicians should first assess for possible sensitizing factors. The nervous system demonstrates plasticity in pathological states, and sustained peripheral nociceptive activity (ie, overuse) may contribute to sensitization.⁶³ Stress, anxiety, depression, fear, impaired sleep, and numerous other factors can also contribute to sensitization, and the clinician should ask about psychosocial influences. The Central Sensitization Inventory may help establish the presence of CS through self-report.⁶⁴ Additionally, clinicians can integrate pressure pain threshold (PPT) assessment into examinations to quantify a patient's pain sensitivity. The PPT is measured by gradually advancing the rubber applicator tip of a pressure algometer towards the target tissue, and measuring the cut-point where the patient subjectively reports a sensation of pain rather than pressure. Testing is done bilaterally, and a remote site is often assessed as well. For example, with a distal biceps brachii tendinopathy, the primary pain location would be expected to have a reduced tolerance to pressure, resulting in lower PPT values; however, the contralateral arm and a remote site (the foot, for instance) should be normal. Reduced PPT values at locations distant from the pathology may suggest aberrant pain processing; potentially implicating CS. Understanding a patient's

Table 1.5. Load-induced Tendinopathy Continuum Considerations⁵²

Stage of Tendinopathy	General Considerations	Imaging Findings	Clinical Factors
Reactive tendinopathy	<ul style="list-style-type: none"> - Non-inflammatory proliferative response in the cell and ECM secondary to acute tensile or compressive overload - Results in short-term thickening of the tendon which reduces stress and increases stiffness - Collagen integrity generally maintained - Capable of reverting to normal with appropriate reduction of load or rest between loading 	<ul style="list-style-type: none"> - Slightly swollen tendon appearance - Increased diameter <p><i>MRI</i></p> <ul style="list-style-type: none"> - Minimal or no increased signal <p><i>US</i></p> <ul style="list-style-type: none"> - Intact collagen fascicles - Diffuse hypoechoicity 	<ul style="list-style-type: none"> - Acute tendon overload - More common in younger population - May be related to moderate overuse in the underloaded tendon (ie, sedentary individual, detrained athletes)
Tendon dysrepair	<ul style="list-style-type: none"> - Similar healing process but with greater ECM breakdown - Increased cellular activity and protein production - Neurovascular ingrowth 	<ul style="list-style-type: none"> - Collagen and matrix disorganization - Swollen tendon <p><i>MRI</i></p> <ul style="list-style-type: none"> - Swollen - Increased signal in the tendon <p><i>US</i></p> <ul style="list-style-type: none"> - Discontinuous collagen fascicle - Focal areas of hypoechoicity - Increased vascularization 	<ul style="list-style-type: none"> - Chronically overloaded tendons in young or older individuals - Localized tendon thickening noted with palpation
Degenerative tendinopathy	<ul style="list-style-type: none"> - Substantial ECM breakdown and disorganization - Neovascular ingrowth - Areas of cell death 	<ul style="list-style-type: none"> - Extensive cellular, ECM and vessel changes <p><i>MRI</i></p> <ul style="list-style-type: none"> - Increased tendon size and intratendinous signal - Focal rather than widespread or diffuse intratendinous change <p><i>US</i></p> <ul style="list-style-type: none"> - Hypoechoic areas with reduced collagen fascicle continuity 	<ul style="list-style-type: none"> - Chronically overloaded athlete - More commonly seen in older individuals - Focal areas of tendon thickening, not necessarily widespread or homogeneous - Frequently related to recurrent history of overload

Abbreviations: ECM, extracellular matrix; MRI, magnetic resonance imaging; US, ultrasound

pain experience is integral to positively modifying it. Even if dysfunction of the symptomatic MTU presents as localized, clinicians should consider the possibility that numerous pain inputs, outputs, and processing mechanisms could be at fault.

trinsic and extrinsic factors that could alter the decision making about possible interventions. Some of the more commonly researched factors include aging, immobilization and/or disuse, co-morbidities, and pharmacologic agents.

Additional Factors Affecting Muscle-Tendon Tissue Tolerances

A number of factors influence the quality and capacity of the MTU to function properly. It is important to understand the physiological effects and clinical implications of various in-

Aging

Aging is a normal process of life. While aging is associated with slowing of various metabolic processes and degeneration of multiple tissues, high levels of activity and performance can be safely achieved in older individuals.

As we age, a reduction in strength and power may occur, due primarily to changes in muscle morphology. Sarcopenia is the term used for loss of muscle tissue due to aging. Specifically, sarcopenia leads to a reduction in the number of muscle fibers and atrophy or reduction in the size of remaining fibers.⁶⁵ This change in muscle size may be responsible for the approximately 10% decline in peak strength per decade after the age of 60, with a greater rate of decline after the age of 75.⁶⁶ Type II fibers appear to be preferentially involved. A greater degree of atrophy is noted in the fast-twitch fibers,⁶⁷ potentially contributing to the reduction in power and increased time needed for older individuals to contract and relax a muscle compared to their younger counterparts. Although these described changes are typical with aging, a sedentary lifestyle, injury, or disease can expedite the rate of muscle degeneration.⁶⁶

A number of changes also occur within the tendon during the process of aging. For example, there is a reduction in cell numbers and synthetic activity in mature versus immature tendon tissue,⁶⁸ with an extremely limited tendon tissue turnover after the age of 17.⁶⁹ Conflicting evidence exists; however, the CSA of tendons appears to remain unchanged with age, while collagen content, fibril diameter, proteoglycan content, and molecular packing all are reduced with age.⁶⁸ The result of the biochemical and structural changes associated with age is a reduced modulus and tendon strength.

Overall, the normal process of aging theoretically leads to a weaker MTU. In considering tissue tolerance, clinicians should understand that older individuals may need to be trained to perform rapid movements requiring power, and the tendon connecting the muscle to the bone may not be able to accept the same strain without injury that a younger patient could.

Immobilization and disuse

As the old saying goes, 'If you don't use it, you lose it'. In the case of muscle and tendon tissue, this statement is quite applicable. Skeletal muscle and tendon are dynamic tissues that require movement to maintain typical function. The capacity for a muscle and tendon to work diminishes rapidly after immobilization or disuse.

Muscle tissue can atrophy within days of immobilization or disuse. It has been suggested that a 20% reduction in muscle CSA is associated with up to a 40% reduction in strength.¹⁰ This ratio is likely related to a loss of contractile proteins due to immobilization, but also an impairment and ineffectiveness of neurologic function. One study examined the effect of disuse by placing a knee immobilizer on the knee of healthy young males.⁷⁰ Within only 5 days, subjects demonstrated substantial reductions in quadriceps muscle CSA, leg lean mass, and strength. The expression of muscle myostatin mRNA, a myogenesis-inhibiting protein, was doubled in the immobilization group. Interestingly, the position of immobilization may play a role in the deleterious effects. When immobilized in shortened positions, muscles demonstrate greater reductions of strength,

mass, and myofibrillar contractile proteins, compared to immobilization in neutral or lengthened positions.⁷¹ Immobilization and disuse affect both type I and II muscle fibers; however, there appears to be a greater relative loss of the slow-twitch type I fibers, given their more frequent activity during daily activities.⁷²

Immobilization can also have significant effects on tendon tissue. The structural and functional changes do not appear as dramatic as in muscle, potentially related to tendon's relatively lower metabolic rate and vascularity. Specific changes related to immobilization include decreased tensile strength, elastic stiffness, and total tendon weight.⁷³ Collagen fibers become thinner and disorganized, cross-linking becomes less prominent, and tenocyte alterations occur. These changes not only affect the structure of tendon in the short term, they also may have longer-term implications for capacity to heal. In a mouse model study, postsurgical immobilization of the Achilles tendon was associated with delayed normalization in load-to-failure studies and significantly lower tendon stiffness, with follow-up being 112 days.⁷⁴ This study reinforces what was already assumed, that a weaker immobilized tendon can tolerate less force prior to rupture. Importantly, negative consequences to immobilization also are noted at the myotendinous junction. The contact area between muscle and tendon cells is reduced by up to 50% following 3 weeks of immobilization, contributing to a fragile point of connection between these two already weakened tissues.⁷⁵ Because of the decreased strength, the myotendinous junction may be predisposed to rupture after immobilization.

These changes are important to understand in the rehabilitation and retraining of persons who have been immobilized, sedentary, or deconditioned. Given the associated negative consequences, required periods of immobilization should be minimized if possible. A gradual progression of load should be incorporated, so as to not increase the risk of rupture, considering the reduced tissue tolerance that muscles and tendons demonstrate following immobilization.

Co-morbidities

As previously mentioned, a number of risk factors exist for developing muscle or tendon dysfunction. While many risk factors can be captured by a thorough subjective history of the current condition (eg, training schedules, changes in loading) or within the examination (eg, leg length discrepancy or muscle length restrictions), some contributing factors may be missed in the context of muscle or tendon injury. Clinicians should be aware that numerous medical conditions can alter the mechanical capacity of the MTU, and adjust interventions accordingly. This section highlights some of the more commonly associated risk factors/co-morbidities.

Diabetes Mellitus

Diabetes mellitus (DM) is a metabolic condition that can increase the risk of developing MTU dysfunction and can affect the musculoskeletal system's capacity to heal. In tendinopathy,

DM is a prevalent condition that negatively affects clinical outcomes. In a number of studies, asymptomatic individuals with DM have demonstrated tendinopathic changes compared to control subjects without DM.⁷⁶ One such study of asymptomatic patients found tendinopathic changes in 89% of patients with DM but in only 24% of patients without DM.⁷⁷ Diabetic tendons have exhibited increased structural abnormality, thickness, volume, and stiffness,⁷⁸ as well as an inhibition of angiogenesis, cell proliferation, and tenogenic differentiation.⁷⁶ Clinically, patients with rotator cuff tears reported greater levels of pain, stiffness, and disability when they also had diabetes than did patients without DM.^{79,80} Managing a patient's DM through lifestyle modification and glucose control can enhance the capacity of muscle or tendon to heal, in turn improving patient outcomes.

Obesity

Obesity is an epidemic across the United States, and is associated with a number of cardiovascular, metabolic, and musculoskeletal conditions. Specific to the MTU, elevated adiposity is a risk factor for developing tendinopathy in both load-bearing (lower extremity) and non-load bearing (upper extremity) tendons. A systematic review found the presence of obesity (measured by body mass index) to be associated with an odds ratio ranging between 1.9 and 5.6 for developing tendon conditions.⁸¹

Structural modifications to tendons associated with obesity include lipid migration into the ECM, impaired interstitial fluid movement, increased thickness, and stiffness.⁸² Mechanisms for tendon dysfunction in the presence of obesity are primarily two-fold. For load-bearing tendons, greater adiposity puts greater demand on a tendon that is inherently weaker and less pliable, leading to overuse or rupture. For non-load bearing tendons, a systemic mechanism is thought to cause dysfunction. With obesity, a low-grade subclinical level of inflammation is present, marked by elevated levels of TNF- α and IL-6.⁸³ Immune mediation cells (ie, mast cells, macrophages) tend to migrate into adipose tissue, resulting in a reduced circulatory concentration level.⁸² The decreased circulatory immune cells, coupled with a reduction in the release of profibrotic factors, leads to an impaired production of type I collagen and reduced capacity for the tendon to repair itself.^{82,84}

Whether it is a risk factor, a hindrance to tendon recovery, or both, clinicians should be aware of the negative consequences obesity may have for the MTU. Weight control, lifestyle modification, and interdisciplinary management should be integrated to optimize MTU tissue tolerance.

Hypercholesterolemia

High cholesterol may predispose individuals to tendon injuries. Studies have found positive correlations between substantially increased cholesterol levels and Achilles tendon thickness⁸⁵ and ruptures.⁸⁶ A number of mechanisms have been

suggested for the correlation. Hypercholesterolemia has been associated with the development of tendon xanthomas (fatty growths), which may contribute to mechanical weakening of the tendon.⁸⁷ Additionally, studies have shown changes to the ECM in rats with hypercholesterolemic serum levels⁸⁸ and reduced baseline elastic modulus and strength⁸⁹ compared to controls. While replication with human studies could confirm the correlation, clinicians should consider the possible biomechanical impairments to tendon tissue in the presence of elevated serum cholesterol levels. Diet and regular exercise could assist in managing cholesterol levels in some cases.

Pharmacologic agents

A number of medications are commonly prescribed for the management of MTU dysfunction, and some medications have been linked to the development of MTU conditions. While all medications come with side effects, it can be helpful for clinicians to review the individual's current and historical medication usage and to be familiar with the drugs' possible interactions on the patient's MTU tissue tolerance.

Anti-inflammatories

Pain is the primary complaint in the majority of MTU pathologies; thus, pain medication is often prescribed to manage the condition. Additionally, some inflammatory processes need to be controlled to avoid prolonging or exacerbating the condition. To address both problems, non-steroidal anti-inflammatory drugs (NSAIDs) are prescribed, such as aspirin (Bayer), celecoxib (Celebrex), ibuprofen (Advil, Motrin) and naproxen (Aleve, Naprosyn). Nonsteroidal anti-inflammatory drugs act to inhibit cyclooxygenase enzymes (ie, COX-1, COX-2), which catalyze pro-inflammatory prostaglandins (ie, PGE₂).⁹⁰ Given these drugs' mechanism of efficacy, pain and inflammation associated with tendinopathy theoretically would be reduced. In a study using rats, NSAIDs were prescribed in the inflammatory phase of tendinopathy, and ibuprofen was shown to inhibit cellular responses and matrix remodeling, negatively impacting the healing process.⁹¹ Similar inhibition of tissue healing occurs after NSAIDs are prescribed for muscle strains, as delays in muscle regeneration and damaged tissue degradation have been reported.⁹² Conversely, some authors found no change in tenocyte activity when NSAIDs were prescribed for human tendinopathic tissue.^{90,93} Another recent study using human subjects found only moderate pain relief from NSAIDs for Achilles tendinopathy, with no positive effect on the reparative process.⁹⁰ With the limited efficacy and numerous known systemic side effects associated with oral ingestion, the authors could not recommend NSAIDs for Achilles tendinopathy.

Corticosteroid injections (CSI) have also been used in the management of tendinopathy, given the need for local pain and inflammatory mediator control. However, while the occurrence is actually quite low, tendon rupture has been associated with CSI. Rupture may be the end result of structural changes such

as collagen disorganization, impairment of fibroblast viability, depletion of stem cells, and reduced mechanical properties associated with local CSI.⁹⁴

Fluoroquinolones

Fluoroquinolones are antibiotics prescribed to manage skin, respiratory, and sexually-transmitted diseases. Commonly prescribed medications include ciprofloxacin (Cipro), gemifloxacin (Factive), ofloxacin (Floxin), levofloxacin (Levaquin), and moxifloxacin (Avelox). While fluoroquinolones do not usually alter the clinical course of MTU pathology, tendinopathy and tendon rupture associated with these antibiotics was initially reported in the 1980s. Incidence rates of 2.4 per 10,000 patient prescriptions for tendinitis and 1.2 per 10,000 for tendon rupture have been reported,⁹⁵ with the Achilles tendon appearing to be the most commonly afflicted.⁹⁶

Matrix metalloproteinases (MMP) are enzymes that serve a role in the maintenance of tendon homeostasis. Fluoroquinolones facilitate MMP-3 in tendon tissue which reduces collagen synthesis through the inhibition of tenocyte propagation.⁹⁷ Pain is the primary complaint of toxicity, with or without additional signs of inflammation.⁹⁸ Time to onset varies widely. Symptoms may be present within hours after initial consumption or 6 months after cessation of the medication, but often appear within a week of initiation.⁹⁶

Statins

Statins are used to inhibit the production of cholesterol. Commonly used statins are lovastatin (Mevacor), rosuvastatin (Crestor), atorvastatin (Lipitor), pravastatin (Pravachol), and simvastatin (Zocor). Despite appropriate dosing, a statin-induced tendinopathy prevalence of 2.09% was reported in one study, with females more commonly affected than males.⁹⁹ Spontaneous rupture has also been reported, primarily of lower extremity tendons, and in some cases bilateral symptoms were observed.¹⁰⁰

The physiological mechanism for statin-induced tendinopathy or rupture is still unclear. A number of plausible theories exist, mostly supporting MMP inhibition interfering with tendon remodeling, reduced tenocyte migration and integrity, and apoptosis inappropriately targeting the tendon ECM.^{100,101} With statin-induced tendinopathy, patients often report pain and tenderness, sometimes with local swelling, within a year (80% note symptoms within the first four months of initiation). Median time to tendon symptoms with statin therapy was 8 months.⁹⁹

DIAGNOSTIC MEASURES AND EVALUATIONS OF THE MUSCLE-TENDON UNIT

Various imaging modalities can serve an integral role in the diagnosis and proper assessment of tissue injury, ruling out competing diagnostic hypotheses, and prognosticating the patient's return to their prior level of function. In recent

years, numerous well-performed diagnostic imaging studies have reported a high proportion of pathology in the asymptomatic population. Informing patients of pathology that may be functionally and symptomatically irrelevant may do more harm than good, and treating pathological tissue that is not causing a patient's functional loss or symptoms is inappropriate. In light of emerging evidence suggesting that imaging may not appropriately or completely describe a patient's condition, it is necessary to incorporate clinical reasoning, patient values, and data clustering in decision making so as not to over, under, or inappropriately depend only on diagnostic modalities. The following section highlights the imaging modalities commonly used for MTU dysfunction.

When an injury to the MTU is suspected, diagnostic ultrasound (US) and magnetic resonance imaging (MRI) provide the greatest diagnostic utility. However, plain-film radiographs are commonly used as a first-line imaging option for painful musculoskeletal conditions. Given the soft tissues included in the MTU, radiography serves the purpose of ruling out various conditions better than it does diagnosing MTU pathology.

Diagnostic Ultrasound

Diagnostic US is becoming more widespread in physical therapy practice for both diagnostic and therapeutic purposes. One study found that by replacing MRI with diagnostic US, billions of health care dollars could be saved.¹⁰² Diagnostic US delivers sound waves through a probe to a target region of tissues, and the received sound waves create an image. Tissues that reflect sound waves well are described as hyperechoic, while tissues that do not reflect sound waves are described as anechoic. Commonly evaluated tissues, in order from hyper to hypoechoic, are bone, ligament, tendon, nerve, and muscle.¹⁰³ Diagnostic US tends to be most helpful for superficial tissues, given its limited depth of penetration. When evaluating rotator cuff pathology, one study found 95% sensitivity, 94% specificity, 97% positive predictive value, and 91% negative predictive value.¹⁰⁴ When evaluating patellar tendinopathy, US demonstrated 87% sensitivity and 82% specificity.¹⁰⁵ Tendinopathic changes found on US include increased tendon thickness, heterogeneity of tendon structure, and diffuse areas of hypoechoicity. A recent systematic review with meta-analysis found that Achilles or patellar tendon abnormality in the asymptomatic population may increase the risk of developing tendinopathy by at least four-fold.¹⁰⁶ In tendinopathy, color Doppler US can be quite useful in identifying hypervascularity. Neovascularization has been associated with the presence of chronic tendinopathies, although the correlation to pain or limited function is weak.¹⁰⁷ While diagnostic utility of US is strong, assessment is fast, the relative cost is low, and it can be used during both active and passive movements, the challenges in assessing deep tissues, the operator error associated with this modality, and the high risk of detecting artifact can limit usefulness in some cases.

Magnetic Resonance Imaging

Magnetic resonance imaging is considered the criterion standard of non-invasive imaging of the MTU, owing to its precision with anatomic detail and soft tissue contrast. The clinical utility of MRI is reduced however, given the expense, time required for image capture, need for a static position to be maintained throughout testing, and often an extended scheduling time. Magnetic resonance imaging works by using a strong magnetic field to align the protons of the countless hydrogen nuclei of the human body. The return to baseline occurs when the magnetic field is turned off, a process that is captured through radio signals and turned into images. A lack of ionizing radiation makes MRI generally safe, assuming no contraindications are present (eg, metal implants, claustrophobia). Normal tendons appear with low signal intensity on conventional imaging sequences. Due to short T2 relaxation times, dark signal void is commonly noted. A sufficiently long echo time and stronger magnetic field may mitigate the challenge by enhancing image resolution, signal-to-noise ratio, and clarifying signal noise.^{108,109} In tendinopathy, MRI will show increased signal intensity and tendon thickening. In T2 weighted images, fluid signal may accompany tearing.¹¹⁰ In evaluating Achilles tendinopathy, MRI had 95% sensitivity, 50% specificity, 56% positive predictive value, and 94% negative predictive value.¹¹¹

Again, while MRI has inherent value to clinical practice, clinicians should consider the substantial proportion of MTU abnormality revealed with MRI in asymptomatic patients, and use findings in combination with additional data when making decisions.¹¹²

Electromyography

Electromyography (EMG) is the evaluation of the electrical activity of muscles. Electromyography data is obtained by either applying surface electrodes to a muscle of interest, or inserting a needling into the muscle to detect the activity at rest, with stimulation or with voluntary contractions. The EMG data can assist in diagnosing nerve pathology, as the amplitude of electrical activity of the given muscle will be reduced in the presence of compressive neuropathies. Electromyography data can also be integrated to assist in developing therapeutic intervention. Numerous studies have evaluated the EMG activity of various muscles during common therapeutic exercises. Identifying the degree of electrical activity of a muscle can be helpful in improving muscle performance and also avoiding activities that may be harmful to the MTU.

For example, after a rotator cuff repair there is a need to limit the degree of voluntary activity of the cuff to avoid a re-tear. Consequently passive activities are preferred and active-assisted movements are used on a limited basis. Using indwelling fine-wire needle electrodes, one study found that purportedly passive activities (using a pulley system or ambulating without a sling) were associated with substantial EMG activity, whereas using a dowel or performing pendulum exercises were associat-

ed with lower EMG activity.¹¹³ Integrating the results of EMG studies into clinical practice can be helpful in reducing unnecessary activity in healing tissues.

Similarly, the results of EMG studies can identify a starting place and target for interventions addressing impaired muscle performance. For instance, in patients with patellofemoral pain, the kinetics and kinematics of squatting movements are altered often in some part due to impaired gluteus medius activity. Distefano and colleagues completed a study using surface EMG to identify gluteus medius and maximus signal amplitude during maximum voluntary isometric contractions (MVIC) of common therapeutic exercises.¹¹⁴ Sidelying hip external rotation ('clam shells') appear to be a mainstay in a clinician's exercise repertoire, however mean signal amplitude (%MVIC) was the lowest of all activities assessed, as compared to sidelying hip abduction or squat based activities. Results from this and similar studies can be incorporated by identifying the degree of muscle performance impairment, and prescribing exercises to match the patient's capacity. For instance, a patient who scores quite low on MMT of the gluteus medius, then lower level %MVIC activities may be more appropriate early on to recruit or isolate the given muscle, whereas high %MVIC activities would likely recruit adjacent musculature to perform the task.

Muscle-Tendon Biopsy and Laboratory Investigations

The previously mentioned assessment options are quite useful especially when symptoms are localized to an MTU. In the presence of muscle or tendon pain that may have a systemic pathophysiology, histopathological assessment may be useful. Muscular dystrophy, polymyalgia rheumatica, inflammatory myopathies, infectious diseases, systemic lupus erythematosus, scleroderma, and thyroid diseases are some conditions that may present with muscle-tendon pain or dysfunction, unrelated to a specifically pathologic MTU.^{115,116} To this end, biopsy of local tissue or retrieval of blood samples may elucidate underlying conditions.

Muscle pains, or myalgias, may be present for various reasons such as soreness from exercise or strenuous activity, as a side effect of medication or chemotherapy, or related to systemic or rheumatic disease processes. Additionally, muscular weakness could be related to injury, myopathic or neurologic disease, endocrine or metabolic processes, etc. In some of these cases, clinical examinations may not recreate the patient/athlete's typical complaint, or identify the true problem, in which case additional testing may be required to identify the pathological condition.

Muscle biopsy can have strong diagnostic utility in neuromuscular and myopathic conditions.^{117,118} The advancement of techniques in tissue acquisition and processing have become more streamlined and more tolerable, although muscle biopsy remains an invasive procedure. Muscle biopsy is often used in conjunction with the clinical examination and additional diagnostic assessments such as imaging. Blood work can similarly

be helpful in identifying underlying pathologic body system processes. In addition to looking at typical blood counts, evaluating levels of inflammatory markers such as C-reactive protein or erythrocyte sedimentation rates and additional enzymatic activity can assist in diagnoses of systematic pathology.¹¹⁵ The presence of elevated inflammatory markers, infection, progressing neurological insult, or additional systemic pathology should result in interdisciplinary treatment plans to identify options to maximize the patient's activity and participation opportunities.

PHYSICAL THERAPY MANAGEMENT OF THE DYSFUNCTIONAL MUSCLE-TENDON UNIT

Conservative management of muscle and tendon dysfunction is the preferred option for treatment in the vast majority of cases. When a dysfunctional MTU prevents normal movement from occurring, physical therapists can use a host of interventions to normalize motion, minimize the impact of dysfunction, optimize function, and minimize the risk of reinjury. To this end, clinical decision making should not rely solely on current trends and best available evidence but also on the individual patient values and clinician experience, each component being weighted equally (Figure 1.9). This section highlights the rationale for use and evidence supporting (or refuting) typically incorporated interventions for MTU pathology.

Exercise

Exercise is the mainstay in the vast majority of physical therapy treatment plans for MTU dysfunction. Returning strength, endurance and mobility to a dysfunctional tissue, improving the performance of a normally functioning tissue, and reducing pain are common indications for using exercise as a treatment. Exercise prescription will change throughout the course of care to safely and progressively increase MTU tissue

tolerance. Given the dynamic functional purpose the MTU serves, exercise prescriptions and relevant patient education to progressively enhance the load tolerance of the MTU should be the priority of treatment plans.

Mechanotransduction

While the effectiveness of exercise is somewhat assumed, the physiological mechanisms for improvement are considered less frequently. One mode by which exercise is effective in enhancing tissue repair and quality is through mechanotransduction. Mechanotransduction is a 3 step process whereby (1) mechanical loading leads to (2) cell to cell communication which in turn stimulates (3) cellular responses (eg, cellular proliferation, altered metabolism).^{119,120} Muscular and tendinous tissue appear to be particularly mechanosensitive, responding to the shearing, compressive, and tensile loads placed upon them. When considering the purpose of an activity, and the proposed exercise to enhance MTU tissue tolerance, clinicians should also be aware of this frequently undetected process, and the implications of excessive, inadequate, or inappropriate MTU loading at the cellular level.

Stretching

Stretching is an intervention used to enhance the flexibility and adaptability of the MTU. While the primary indication for MTU stretching is a mobility deficit, stretching may also play a role in pain modulation and muscle performance. The neural and physiologic considerations of static and dynamic stretching have been described succinctly in the past.^{121,122} Sustained stretching contributes to MTU elongation through numerous processes such as the creep phenomenon, where static strain (load) over time creates tissue deformation. Interestingly, while each mode of stretching is associated with increased joint ROM, increased motion may be related to an increased tolerance to stretch, rather than to increased muscle extensibility.¹²³ In fact, a recent review of 26 studies evaluating stretching, with durations up to 8 weeks, found no remarkable changes in muscle-tendon properties (joint resistance to stretch, muscle architecture, muscle stiffness, tendon stiffness), suggesting the majority of early changes in extensibility and tolerance to extensibility occur at the sensory level.¹²⁴ Common forms of stretching include static, ballistic, passive, and proprioceptive neuromuscular facilitation (PNF).

In a recent study evaluating the effects of acute static, ballistic, and PNF stretching on MTU properties, the authors found each mode of stretching increased ROM, and decreased passive resistive torque, muscle stiffness, and muscle-tendon stiffness, with no clinically relevant between-group differences.¹²⁵ Although static stretching has a dose-dependent effect on stretch-induced force loss (the longer a stretch is held, the lower the immediate strength as measured by EMG), dynamic stretching may improve physical performance measures, such as vertical jump height and velocity.¹²⁶ The inherent challenge

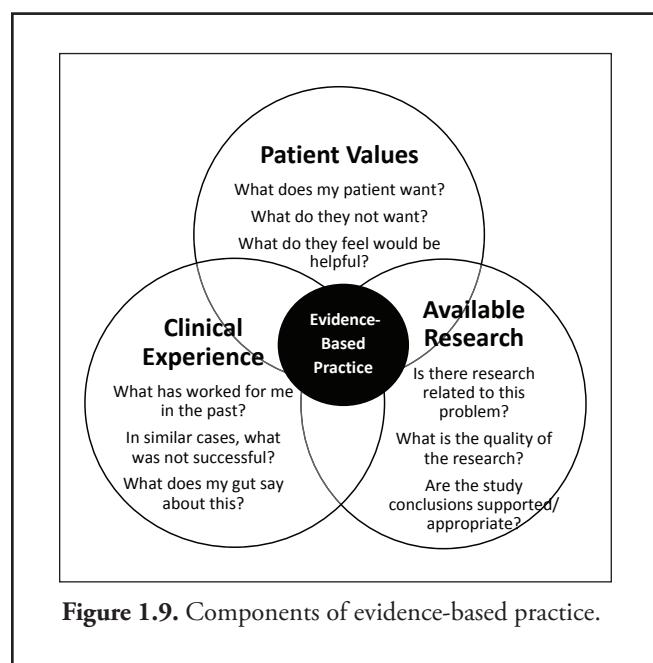


Figure 1.9. Components of evidence-based practice.

posed is that stretching may assist a muscle in becoming more compliant with required demands, enhancing capacity for sport-performance, but stretching also may contribute to acute declines in muscle activity, negatively impacting sport-performance. The lack of studies evaluating appropriate dosage can make it difficult to decide how to stretch an MTU. Clinicians should identify the primary impairment, recognize the possible advantages and disadvantages of stretching for activity performance, and subsequently prescribe the safest and most effective type of stretching.

It is also important to determine when stretching should not be incorporated into a treatment plan. In acute muscle injuries, for example, the inflammatory process and related collagenous deposition may be delayed or less effective if tissues are immediately stretched and not allowed to heal. Additionally, while the presence of mobility deficits suggests the need to improve movement restrictions, stretching may be inappropriate for certain conditions such as insertional tendinopathy. When stretching a tendon into end range, the articular surface of the tendon's insertion is more susceptible to compressive load due to abutment against bony prominences (Figure 1.10).¹²⁷ Compression is generally not well tolerated by tendons, but in degenerative conditions, bony changes at the insertion site also may occur, contributing to a rougher osseous surface. Compressing the tendon against an irregular surface theoretically could lead to structural weakening.

Contraction specific considerations

The type of exercise prescribed for MTU pathology depends on various factors, such as the specific health condition, tissue healing timelines, symptom irritability, tissue capacity, probable compliance, task requirements, and goals. Therefore, it is not possible to provide a specific progression protocol and maintain clinical relevance for a wide proportion of patients. The following section highlights considerations for particular exercise mode prescriptions including evidence supporting

their use. Readers are cautioned to remember the importance of modifying exercise prescriptions based on the above variables, as well as on patient response and required dosage to facilitate continued progression of MTU tolerance.

Isometric exercise

Isometric exercise occurs when external load equals internal force production, resulting in muscular activity with no visual movement. Commonly, isometrics are prescribed when movement may be harmful or when compensation is so likely that recruiting the muscle without movement is preferred. Some examples would be postoperative situations or after acute injury, where scar tissue and immature collagen fusion may not occur if excessive movement occurs. After knee injury, when quadriceps muscle activation has been shown to be reduced,¹²⁸ isometric exercise may be ideal to re-integrate and target neuromuscular control. Hold times can be altered depending on the functional need. The deep neck flexors, for illustration, are a phasic group of muscles active during static sitting and short duration holds would not be sufficient to enhance task-specific needs.

Additionally, isometric exercise may have a role in reducing pain. A systematic review with meta-analysis found isometric exercise to be useful in reducing pain in healthy experimental subjects as well as in the chronic pain population (shoulder pain and fibromyalgia, primarily).¹²⁹ Based on the reviewed studies, submaximal exercise (20–25% MVIC) for up to 5 minutes was associated with significant pain reduction with large pooled effect sizes reported. A number of studies have evaluated the effectiveness of isometrics for patellar tendinopathy. In a small sample of volleyball players, a single bout of isometric exercise was associated with immediate pain reduction lasting up to 45 minutes, increased MVIC, and reduced cortical inhibition.¹³⁰ In a recent study, short duration holds (24 sets of 10 second holds) and longer duration holds (6 sets of 40 seconds) resulted in equally significant improvement in pain and quadriceps muscle function.¹³¹ Importantly, isometric exercise may be more effective than other forms of exercise for short-term pain relief for in-season athletes.^{132,133}

Eccentric exercise and tendinopathy

Eccentric contractions can generate substantial muscle tension, which is integral during functional and sport-related tasks. The frequent fluctuations between concentric and eccentric movements require neuromuscular control, muscle capacity, movement capacity, and training to be carried out safely. Eccentric exercise prescriptions can play an important role in the rehabilitation of MTU pathology as well as in the prevention of injury.

Eccentric exercise has been used with efficacy for decades in the management of chronic tendon pathology. Eccentric exercise for tendinopathy rehabilitation emphasizes a slow and controlled lowering phase, usually only of the involved limb, while the contralateral limb assists during the concentric portion of movement. Alfredson's classic protocol for Achilles ten-

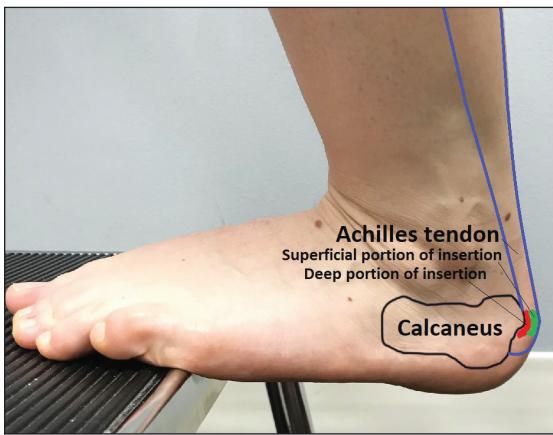


Figure 1.10. Achilles tendon insertion.

dinopathy of 3 sets of 15 repetitions with the knee straight and knee bent twice daily has gained widespread clinical use for different body regions.¹³⁴ During the eccentric phase, pain is expected, and load is increased until pain is present, however pain should not remain after exercise. Various protocols have been developed; however, when reviewing contemporary evidence, it appears a specific protocol is less important in achieving a positive outcome than creating specific prescriptions based on patient presentation. Considering the previously discussed tendinopathy continuum,⁵³ a patient with reactive tendinopathy and an acutely overloaded tendon likely would benefit more from relative unloading, which may include isometric or lower intensity exercise, than from eccentrically straining the involved tendon. Conversely, an individual with degenerative tendinopathy may benefit from increasing load capacity of the healthy portion of the involved tendon through eccentric exercise. To this end, proper prescription requires clinical reasoning incorporating various patient-specific factors rather than being based solely on a diagnosis.¹³⁵

The mechanism of how eccentric exercise assists in managing chronic tendinopathy is an ongoing area of research. One proposed mechanism for improvement has been alteration of the tendon itself, creating a more normalized structure. Studies have shown that a 12-week eccentric exercise program was associated with decreased tendon thickness, decreased neovascularization, and normalized tendon structure, outcomes that were associated with patient satisfaction at long-term follow-up.^{136,137} However, a recent systematic review suggested that strong evidence refutes the notion that observable structural changes are the primary explanation for improvement in tendinopathy.¹³⁸ If tendon structure is not necessarily linked to symptoms, it is unclear what eccentric exercise actually does to lead to improvement. The authors of the original continuum model suggested that exercise may be effective for tendinopathy, not by changing the structure of the degenerated tendon, but by improving the quality and capacity of the healthy tendon. Their theory was that exercise for tendinopathy effectively treats the donut (area of typical fibrillar structure) not the hole (area of disorganization).⁵⁴

In recent systematic reviews, eccentric exercise was reported to be effective in managing pain and improving function and strength in patients with tendinopathy of the upper¹³⁹ and lower extremities.¹⁴⁰ However, as the authors pointed out, while eccentric exercise consistently enhances pain and function, between-group differences are not as large when compared to other interventions. In some cases, eccentric exercise should be modified to enhance effectiveness. For example, with insertional tendinopathy, moving through full ROM may increase compressive load on the insertion, exacerbating the condition. Improved outcomes with Achilles tendinopathy were noted when patients went from a single-limb heel raise lowering back to the ground (neutral dorsiflexion) rather than into end range dorsiflexion.¹⁴¹

Eccentric exercise and muscle strains

Muscle injuries occur when capacity is less than the required load, which frequently occurs during high-intensity and dynamic movements. Increasing muscle capacity to tolerate more load should include progressive eccentric load, when tolerated by symptoms as well as when tissue healing timelines suggest the prescription is safe. A majority of available literature describing eccentric exercise for muscle strain rehabilitation relates to the hamstring; however, principles could be applied throughout the body.

Related to hamstring injury, eccentric exercise appears to have positive effects on hamstring strength, hamstring:quadriceps ratios, and injury prevention.¹⁴² Numerous options exist for eccentric exercise, such as lunges, squat and split jumps, plyometric box jumps, deadlifts, and ladder drills. However, as Heiderscheit and colleagues proposed, a progression to these higher level eccentric exercise tasks requires a phasic advancement, all while taking into consideration the quality of movements with lower level activities, pain, and injury site management.¹⁴³ Phase I of muscle strain rehabilitation emphasizes protection of scar development, minimizing atrophy, and avoiding excessive lengthening of the hamstrings. Phase II goals include regaining painfree strength working towards lengthened positions as tolerated, developing neuromuscular control of the trunk and pelvis, but still avoiding active end-range lengthening if weakness is present. Phase III goals include being symptom free in all activities, normalizing strength through full ROM at various speeds, continuing to improve neuromuscular control and postural stability during sport-specific movements, although full intensity should be avoided if symptoms persist.¹⁴³ Complete recovery is important, because hamstring injuries have a notoriously high recurrence rate.

Nordic curls and single-limb windmills are commonly prescribed to load the hamstrings eccentrically. While Nordic curls (Figure 1.11) eccentrically stress the hamstrings, clinicians should consider the possibility of compensation by the uninvolved limb, as well as the less functional nonweight-bearing position. Single-limb windmills (Figure 1.12) are also prescribed for eccentric hamstring loading. This task requires substantial balance with gluteal, trunk, and transverse plane stability. While more functional than Nordic curls, they present more opportunity for compensation. The important consideration is that either exercise eccentrically loads the hamstrings. Each could be effective in managing hamstring strains; however, each could also be inappropriate, depending on where the patient is along the recovery spectrum. The clinician's job is to modify exercises based on the patient's MTU capacity, to avoid overload or underload. While available evidence for other muscle injury rehabilitation may not be as thorough and detailed as Heiderscheit and colleagues presented, the same principles apply: protect the injury initially while managing pain and maintaining muscle performance, normalize impairments at the BSF level



Figure 1.11. Nordic curls.



Figure 1.12. Single leg windmills.

while improving neuromuscular control of additional adjacent segments, and gradually return to sport/activity.

Heavy slow resistance training

Heavy slow resistance (HSR) training has become a commonly used form of exercise in the management of chronic lower limb tendon dysfunction. Heavy slow resistance incorporates a combination of eccentric and concentric activity in a gradually progressive program that reduces repetitions and increases load as time goes on. Similar to eccentric exercise prescription, pain is allowed during activity, as long as pain is not present when exercise ceases. Depending on the source used, the concentric and eccentric phases usually last 3 seconds each, emphasizing control of the given movement. In patients with patellar tendinopathy, a 12-week bout of HSR was associated with increased fibril density and collagen network turnover, decreased tendon stiffness, mean fibril area, and neovascularization.^{144,145}

Currently, the evidence related to HSR for tendinopathy is limited but promising. After 12-week programs, patients with patellar tendinopathy had significant improvements in pain and function. When HSR was compared to eccentric training as a treatment for Achilles tendinopathy, both groups had significant improvement in pain, function, and tendon structure.¹⁴⁶ Notably, patient satisfaction was greater in both the short term¹⁴⁶ and long term¹⁴⁵ for the group performing HSR compared to other interventions (eccentric exercise or CSI). However, early results for HSR compared to CSI for the management of rotator cuff tendinopathy suggest statistically non-significant adjusted mean group differences.¹⁴⁷ While more research is necessary for HSR, early outcomes suggest good efficacy and patient-reported satisfaction. This is important in exercise prescription, because certain protocols have notoriously lower compliance rates. Current evidence suggests HSR may be a viable option for patients with lower limb tendinopathy.

Manual Therapy

Manual therapy includes a number of skilled hand movements used primarily to enhance the mobility and performance of joint and soft tissues, and to decrease pain. As discussed previously, mobility restrictions are a risk factor for developing MTU dysfunction, making manual therapy a logical intervention in the management of pathology. The most common forms of manual therapy for MTU dysfunction are soft tissue mobilization (STM) and joint mobilization/manipulation.

Proposed mechanisms of action

Manual therapy can be quite efficacious, but is frequently more useful as adjuvant treatment to exercise and education than when used alone. How manual therapy works is an ongoing area of research, although numerous papers have identified several possible mechanisms.^{148,149} When a mechanical manual therapy technique is applied by a clinician's hands to a patient's body, local biomechanical effects are felt at the site of application, as well as potent local neurophysiological effects, at the spi-

nal and supraspinal levels.¹⁴⁸ Hands-on techniques, particularly joint mobilization/manipulation, appear to have a widespread effect on pain sensitivity through descending inhibition.^{150,151} To this end, it should be remembered that there is more to manual therapy than where and how you use your hands.

Soft tissue mobilization

Mobilization of soft tissue restrictions can enhance length-tension relationships and the MTU's capacity to function appropriately. Soft tissue mobilization encompasses a wide variety of techniques, although massage, myofascial release, PNF, and deep friction mobilization (DFM) appear to be the most commonly used and researched related to MTU pathology.

Massage

Massage and myofascial release allow muscle relaxation and elongation, and are frequently used to enhance muscle performance and recovery, and to prevent injury. Proposed physiological mechanisms include increasing tissue temperature and pliability, reducing abnormal collagen crosslinking, normalizing motor neuron activity, and reducing lactic acid concentrations, among others.^{152,153} A literature review suggests caution when applying these mechanisms to clinical practice, as available research is conflicting on the efficacy of massage.¹⁵² However, when evaluating the studies included within the review, subjects were described as typically healthy volunteers or athletes, so the conclusions of the review would not necessarily apply to a pathologic population. Dosage of massage will depend on the purpose, muscle group(s), and degree of impairment, but is usually carried on until a change in tissue quality is observed.

Proprioceptive neuromuscular facilitation

A variety of techniques in clinical practice are related to PNF. Hold-relax and contract-relax are commonly integrated by having a patient either hold or move through a pattern against resistance for a period of time; after contraction, the patient is passively taken into the additional ROM gained. Mechanisms for increased ROM related to PNF techniques are usually attributed to autogenic or reciprocal inhibition.

A literature review described clinically useful dosages.¹⁵⁴ The authors found a combination of shortening and static contractions to be more effective than either one used independently. A minimum of one submaximal repetition, held for at least 3 seconds, twice weekly, is necessary to augment ROM. Moving the limb using a slower velocity may help to avoid increased stiffness through the stretch reflex or increased viscous resistance. The effects of PNF may be augmented when preceded by STM to enhance available ROM,¹⁵⁵ while assisted or unassisted techniques may provide similar outcomes.¹⁵⁶

Deep friction mobilization

Deep friction mobilization is an STM technique used to treat focal areas of MTU dysfunction, primarily tendinopathy.

ic changes. Classically described by Cyriax, DFM includes the application and maintenance of pressure and simultaneous movement transverse to the fiber orientation of the tissue of interest.¹⁵⁷ For example, at the patellar tendon, the clinician would sustain pressure on the tendon while rubbing his or her finger(s) in a medial/lateral direction, compared to the vertical orientation of the patellar tendon. This process is thought to create a micro-inflammatory response, disrupting abnormal collagen cross-linkage, increasing local blood flow, and subsequently allowing a pathological muscle/tendon tissue to have an opportunity to heal.

A review of available literature revealed limited, low quality evidence with conflicting conclusions supporting DFM for tendinopathy. A systematic review in 2012 found 8 trials, none using DFM in isolation, and stated that when used as a component of treatment, DFM may be effective for lateral epicondylalgia and supraspinatus tendinopathy.¹⁵⁸ Additional investigations related to patellar tendinopathy suggest that when used in conjunction with other interventions, DFM may have an additive effect,¹⁵⁹ whereas DFM by itself is not more effective for patellar tendinopathy than other options¹⁶⁰; however, small sample sizes limit generalizability. While frequently performed in conjunction with other interventions, the effect of isolated DFM for MTU pathology is uncertain. Again, typical dosage is not well defined. Bouts of 30 to 60 seconds are common, usually not longer than 5 minutes during a session.

Joint mobilization and manipulation

As discussed earlier in this monograph, mobility restrictions may be a risk factor for or appear as a consequence of MTU pathology. When an MTU is hypomobile, so too will be the joint, and vice versa. It could be hypothesized that when a joint is restricted, the associated MTUs have to work harder from a biomechanical disadvantage to accomplish the same task. If this is true, using joint mobilization to enhance the capacity of the MTU to function appears reasonable, when necessary.

In addition to the biomechanical effect of enhancing movement, joint mobilization and manipulation are associated with a number of neurophysiological, psychological, and pain reducing effects. Several schools of thought exist related to the use of joint mobilization techniques, some arthrokinematics-based and others based on symptomatic presentation. Regardless of the approach, the benefit of joint mobilization (thrust or non-thrust techniques) is typically short term and is seen when used as a component of a more robust treatment plan incorporating education, exercise, etc, to address additional factors contributing to the patient's primary complaint.

To date, few studies have described joint-directed manual therapy techniques as a primary intervention for MTU dysfunction. One exception is for lateral epicondylalgia, where the use of joint mobilization has demonstrated efficacy in reducing pain and enhancing function.^{161,162} Interestingly, joint mobilization at the wrist, elbow, and cervical spine may each

have efficacy for the condition. In particular, mobilization with movement, when a patient performs a painful grip and the therapist holds a pain relieving joint glide (Figure 1.13), appears to be efficacious for lateral epicondylalgia. Based on a recent systematic review with meta-analysis, joint mobilization of the shoulder complex and cervicothoracic spine, used as part of a comprehensive treatment plan, may have an effect of reducing pain for persons with rotator cuff tendinopathy, although its effect on function is unclear.¹⁶³ In the case of a posterior capsule restriction, which frequently has been labeled as contributing to rotator cuff impingement during overhead movements, anterior-posterior glides to the glenohumeral joint may prove effective (Figure 1.14). In a case report of a patient with a massive irreparable rotator cuff tear, use of sternoclavicular joint mobilization was associated with substantial improvement in pain, ROM and function.¹⁶⁴ Very few papers have described the use of joint mobilization in the lower extremity for tendinopathy or muscle pathology. A number of case reports have described positive outcomes in pain and function when joint mobilization was integrated with treatment plans for patients with recalcitrant symptoms of patellar, Achilles, and peroneal tendinopathies.¹⁶⁵⁻¹⁶⁸

Considerations with manual therapy and research

Like the majority of therapeutic interventions in physical therapy practice, manual therapy is typically integrated as a small component of a comprehensive treatment plan. Much of the research that isolates a single manual therapy technique (eg,

DFM or joint mobilization) subsequently loses some of its clinical relevance. Additionally, dosage of manual therapy is often dependent on both the clinician and patient, and to when a patient's pain or stiffness are reduced. Standardizing the procedure, as is done in much of the available literature, again becomes less clinically relevant. However, despite the inherent clinical irrelevance of some research, researchers have the difficult task of identifying preferred dosage and most effective techniques in the effort to optimize and streamline treatment. Where a dearth of evidence exists for manual therapy (which is the case in some MTU pathology), clinicians should integrate clinical reasoning, experience, and patient values in determining if manual therapy is relevant in improving the patient's current level of function.

THERAPEUTIC MODALITIES

Therapeutic modalities are used in physical therapy practice primarily to reduce pain and improve tissue healing. Historically used with high frequency, clinical practice trends have shifted to a reduced use of modalities, owing primarily to the lack of strong evidence justifying their widespread use. Additionally, many therapists believe that the use of physical modalities may facilitate the perception that passive treatments lead to healing, while, in fact, programs are preferred that involve active participation in recovery. Despite the general movement away from therapeutic modalities, it is important to take an unbiased approach to identify the purpose, evidence, and clinical decision making behind the use of modalities in the management of the dysfunctional MTU.



Figure 1.13. Mobilization with movement at the elbow.



Figure 1.14. Anterior to posterior glide of the glenohumeral joint.

Electrical Stimulation

Electrical stimulation (e-stim) is a multi-purpose intervention used to enhance MTU tissue tolerance. E-stim is most frequently used in musculoskeletal practice to reduce pain, but also has a place in tissue/wound healing and improving muscle performance through neuromuscular e-stim (NMES) and biofeedback.

Related specifically to increasing MTU performance, e-stim can enhance motor recruitment. When volitional control of muscle is impaired, as in the quadriceps muscle after ACL reconstruction, NMES can help to recruit additional motor units not activated by the patient's contraction. Various factors of the stimulation can be manipulated, such as the pulse duration and frequency, or duty cycle, to enhance the expected outcome in a comfortable manner. Much of the research related to NMES centers around the quadriceps muscle. In a systematic review, NMES plus exercise was more effective in improving quadriceps muscle strength after ACL reconstruction than exercise alone.¹⁶⁹ In a narrative review of a single electronic database, the authors suggested torque production could be improved and fatigue and discomfort could be minimized with the use of NMES.¹⁷⁰ The authors noted pulse duration of 400-600 µs and a pulse frequency of 30-50 Hz were optimal in achieving positive outcomes. Beyond use for the quadriceps muscle, a recent Cochrane review suggested NMES may be effective in treating muscle weakness in persons with advanced progressive diseases.¹⁷¹ Based on available evidence, in the presence of a pathological MTU and resultant weakness, NMES may be used to enhance volitional control and improve strength in a comfortable and effective manner.

Therapeutic Ultrasound

Therapeutic US works by converting electrical energy to acoustic energy, which through processes such as microstreaming and molecular collision contribute to increased cellular activity and metabolism. Thermal effects of continuous therapeutic US are thought to include increased blood flow, reduced muscle spasm, and increased soft tissue extensibility, and the non-thermal effects of pulsed US are thought to enhance tissue repair through altering cell membrane structure, function, and permeability.

While basic science studies using rat models have reported the effectiveness of US, clinical effectiveness appears to present different results. One systematic review of 35 studies found little evidence that active US is more effective than placebo US in treating pain or enhancing tissue repair.¹⁷² More recently, a systematic review with meta-analysis reported US provides no additional benefit in treating rotator cuff tendinopathy¹⁷³ and multiple studies have reported that US does not hasten or enhance muscle regeneration after injury.^{174,175} Despite the theoretical mechanisms of action and basic science studies, clinical studies related to therapeutic US suggest the intervention does

not consistently enhance MTU tissue tolerance. Thus, therapeutic US for the management of MTU pathology is not advised.

Low-Level Laser Therapy

Low-level laser therapy (LLLT) is commonly used to modulate pain and tissue healing. Through the emission of light (infrared or near-infrared) and partial absorption from underlying tissues and cells, LLLT has been theorized to increase cell proliferation and migration, growth factor and inflammatory mediator production, and tissue oxygenation, although consistent mechanisms of action lack clarity.

In 2010, a systematic review with meta-analysis reported strong evidence for positive outcomes related to LLLT in treating tendinopathy.¹⁷⁶ In 2015, a systematic review with meta-analysis specific to LLLT for shoulder tendinopathy reported that LLLT can offer clinically important pain relief and facilitate more rapid tissue healing when used alone or with additional interventions.¹⁷⁷ However, in the most recent Achilles tendinitis clinical practice guideline, the strength of recommendation for LLLT was downgraded from B (moderate) to D (conflicting), suggesting recent studies may not show results as consistently effective as earlier papers.¹⁷⁸ A systematic review in 2014 related to skeletal muscle repair suggested that LLLT was an excellent option in the short term for muscle injuries.¹⁷⁹ In the studies reviewed, positive effects were reportedly correlated to a reduction in the inflammatory process, modulation of growth factors and myogenic regulatory factors, and increased angiogenesis.

Given the purported effects, LLLT would appear to be a reasonable intervention for enhancing MTU tissue tolerance. Available evidence suggests LLLT may augment the recovery process for MTU dysfunction; however, readers are cautioned to recognize the prevalent heterogeneity in treatment parameters.

Trigger Point Dry Needling

Trigger point dry needling (TDN) has gained substantial popularity in recent years. Trigger points are hyperirritable bands of skeletal muscle and fascia that are painful under compression and may or may not refer pain in a characteristic referral pattern, depending on whether it is active or latent. A number of proposed models exist for the development of trigger points, with peripheral and central contributions being implicated.¹⁸⁰ Trigger point dry needling uses a fine filiform needle to penetrate the skin, underlying trigger points, and adjacent soft tissue to reduce pain and improve mobility, assisting in optimizing function. Physiologically, TDN is thought to work by increasing blood flow, restoring sarcomere length and muscle length-tension relationships, decreasing spontaneous electrical activity, reducing nociceptive sensitizing agents, increasing beta endorphins levels, TNF- α , COX 2, and affecting the CNS in a widespread pattern.¹⁸¹ Although numerous techniques exist, it

is common to insert the needle into the tissue of interest (ideally creating a local twitch response), withdraw the needle slightly, redirect, and re-advance the needle into the tissue in a pistonning method.

Several reviews have evaluated the effectiveness of TDN for musculoskeletal disorders.¹⁸²⁻¹⁸⁵ While the conclusions are promising, confidence in using TDN should be tempered when truly dissecting the methods, pooled data, and effect sizes of individual studies that have been combined in these reviews. Results are typically limited to short-term outcome follow-ups, TDN is often compared to placebo, control, or sham TDN, and other intervention groups are frequently as effective, if not more so. While TDN could help in managing pain, and potentially enhancing MTU mobility, allowing for optimal movement capacity, clinical outcomes are not consistently superior to other options. Trigger point dry needling is typically used in conjunction with other interventions addressing additional BSF impairments,¹⁸⁶ and as with any therapeutic modality, clinicians should consider using TDN the minimum amount necessary to enhance MTU tissue tolerance and facilitate an active patient-directed recovery.

MEDICAL MANAGEMENT OF DYSFUNCTIONAL MUSCLE-TENDON UNITS

A variety of medical management options are afforded to individuals with MTU pathology. In many cases, the options listed below tend to be used either in conjunction with additional conservative management or when conservative management has not been deemed successful. Clinicians should be aware of other commonly used treatment options to enable interdisciplinary communication and optimize treatment options for patients after the MTU has exceeded its tolerance and become dysfunctional.

Pharmacotherapy

Since muscle-tendon unit dysfunction often presents clinically as a painful condition, oral medication typically is prescribed to manage pain and inflammatory processes. Orally ingested medication is easy to use, patient guided (taken as needed, in some cases), and effective in reducing pain. However, a number of side effects can be associated with oral medication, which enters the bloodstream in a widespread and non-selective fashion. With acetaminophen and NSAIDs, clinicians should be concerned with the potential mild to severe adverse effects, generally dose-dependent, on the gastrointestinal, cardiovascular, and renal systems.

When evaluating the evidence regarding NSAIDs for MTU dysfunction, the risk of adverse events and potential delay or inhibition of the typical healing processes (as mentioned previously) should be balanced with the potential usefulness. Current evidence appears to be conflicting in this regard, creating challenges for the clinical decision-making process. In a re-

cent systematic review with meta-analysis, NSAIDs were found helpful in the short term to reduce loss of strength, soreness, and circulating creatine kinase levels after acute muscle injury.¹⁸⁷ A systematic review with meta-analysis of the effects of oral NSAIDs on rotator cuff tendinopathy found low to moderate short-term improvements in pain, equivalent in some cases to the effects of CSI.¹⁸⁸ The review found that NSAIDs were not effective in improving patient-reported functional levels. Although a brief duration prescription of NSAIDs for acute tendon or muscle injury may be indicated in the short term, no clear evidence appears to support the use of NSAIDs for treatment of chronic MTU dysfunction in the long term.¹⁸⁹ Notably, NSAIDs for muscle strains, while effective in managing pain in the short term, may actually lead to worse outcomes and tissue inhibition in the long term.¹⁹⁰

Injectables

Numerous injectable treatment options exist for the management of local MTU dysfunction. Injections can help to manage a patient's pain and enhance tissue healing. There seems to be an emphasis on studying the efficacy of injectable treatments, given the relatively non-invasive nature and the positive results to date in the short term with current options. While not meant to be inclusive of all options and available data, the following section will highlight commonly used injectable treatment options that may serve an adjunctive role in MTU intervention.

Corticosteroids

The primary intention of CSI is to reduce pain. Through inhibition of inflammatory mediators, corticosteroids also may modify inflammatory processes. Given the benefit of targeted rather than enteral administration, CSIs are used for peripheral conditions such as tendinopathies, without potential systemic side effects (eg, gastrointestinal irritation, dizziness). Common preparations may include Cortisol, Prednisone, Methylprednisolone, Triamcinolone, Dexamethasone, and Betamethasone.

While the proposed effects of CSI make sound theoretical sense, the clinical utility is questionable, particularly when compared to other interventions. In a systematic review evaluating the effects of CSI for tendinopathy, although statistically significant improvement in short-term pain relief was noted, the intermediate and long-term outcomes frequently were not better and in some cases (lateral epicondylalgia and rotator cuff tendinopathy) were actually worse than other treatments or no treatment at all.¹⁹¹ In a recent single-blinded randomized study evaluating exercise and education versus CSI versus control in the management of gluteal tendinopathy, education and exercise performed better in both the short and long term compared to corticosteroid injection.¹⁹² Moreover, in an economic evaluation study of lateral epicondylalgia, physical therapy by itself was found to be more cost effective than CSI by itself or CSI combined with physical therapy, suggesting that

physical therapy should be the preferred first-line treatment for the condition.¹⁹³ Although CSI may provide short-term pain relief, current evidence suggests a general lack of intermediate or long-term efficacy. When assessing the risk to benefit ratio, clinicians also should consider the infrequent but real possibility of structural weakening of the tendon itself, and the possibility of tendon rupture related to CSI.

Platelet rich plasma

Platelet-rich plasma (PRP) is an autologous blood derivative used to enhance tissue healing, as it has a concentration of platelets greater than that of typical blood. A number of basic science studies have been performed to identify the physiological rationale for its use. In vitro studies in tendinopathy have shown PRP to induce proliferation of tenocytes and tendon stem/progenitor cells, facilitate tenocyte differentiation, enhance collagen synthesis, induce the release of hepatocyte growth factor, which has an anti-inflammatory effect, and enhance coagulation and protease activation (that play an important role in antibiotic effects).¹⁹⁴ Platelet-rich plasma also has been associated with enhanced myogenesis in controlled laboratory studies, potentially enhancing tissue recovery after a muscle injury.¹⁹⁵ Related to the theoretical biological processes associated with tissue healing, and the lack of adverse events, PRP is frequently used in orthopedic and sports medicine settings.

The clinical efficacy of PRP for MTU dysfunction may not be as strong as its widespread use suggests. The evidence supporting PRP for tendinopathy is conflicting, depending on which article is read. One meta-analysis of RCTs reported good evidence to support PRP for tendinopathy,¹⁹⁶ whereas another systematic review with meta-analysis (published the same year) noted PRP to be more effective than control for tendinopathy, but also stated the sample sizes of reviewed studies were too small to determine clinically meaningful treatment effects.¹⁹⁷

For acute muscle injuries, PRP may not yet have strong supportive evidence. As a recent systematic review with meta-analysis pointed out, while some evidence exists to support a reduced return to sport duration with PRP, the methodological quality of studies was low and risk of bias was high.¹⁹⁸ When considering high quality studies only, the authors found non-significant findings in return to sport or reinjury rates, muscle performance or flexibility, or imaging studies. The authors concluded the evidence supporting PRP for acute muscle injuries should be considered low or very low quality. Finally, a Cochrane review investigated platelet-rich therapies for musculoskeletal soft tissue injuries.¹⁹⁹ While the authors noted substantial heterogeneity in the methods of the reviewed studies, pooled data suggested no noteworthy differences between platelet-rich therapies and comparison interventions at short, medium, and long-term outcomes. In summary, while biological and laboratory studies support tissue healing properties, and integration of PRP into clinical practice appears to increasing in recent years, the current evidence does not necessarily support its widespread use.

Prolotherapy

Prolotherapy is a treatment option that has gained popularity in recent years. It is indicated for the treatment of painful musculoskeletal conditions and to enhance the strength of connective tissues. Prolotherapy involves the injection of an irritant, most commonly dextrose, at the local site of pain or tissue injury to facilitate an inflammatory cascade and tissue healing. Dextrose is thought to up-regulate platelet-related growth factors, increase cell and DNA synthesis and cell proliferation, consequently contributing to increased ligament size and mass, repair of articular cartilage, and strengthening of ligament and tendon insertion sites in the bone.^{200,201}

While many basic science and efficacy studies are based on animal models, a number of systematic reviews and meta-analyses have reported clinical benefits for the use of prolotherapy as part of a multimodal treatment plan. Specifically, dextrose prolotherapy has demonstrated benefits for rotator cuff tendinopathy, lateral epicondylalgia, plantar fasciosis, Achilles, and patellar tendinopathy.²⁰¹⁻²⁰³ In a rat model evaluating contusion-induced muscle injury, dextrose prolotherapy was associated with suppression of macrophage activity and increased muscle satellite cell regeneration, suggesting that injections may aid in muscle recovery as well as for tendon or joint dysfunction.²⁰⁴

Extracorporeal Shockwave Therapy

Extracorporeal shockwave therapy (ESWT) uses acoustic sound waves to facilitate enhanced tissue healing. Primary modes of shockwave delivery are electromagnetic, electrohydraulic, and through piezoelectric principles.²⁰⁵ Extracorporeal shockwave therapy has been studied for a variety of conditions, but with regard to musculoskeletal conditions, it appears to be indicated primarily for tendinopathy and bone disorders. In a rat model, ESWT stimulated regeneration of skeletal muscle tissue and accelerated the healing process.²⁰⁶ A number of possible mechanisms of action have been reported, but generally for tendinopathy, it is thought that ESWT heightens the metabolic activity of tenocytes, facilitates improved collagen type I synthesis, and decreases synthesis of MMPs and interleukins.²⁰⁷

A number of systematic reviews have examined the efficacy of ESWT for various conditions, and importantly, many reviews highlight its safety. One review examining the effects of ESWT on soft tissue conditions reported evidence for improvement in plantar fasciitis and calcific tendinitis, with the results being dose dependent.²⁰⁸ Higher doses were associated with greater gains, while lower doses led to worse outcomes for lateral epicondylalgia and rotator cuff syndrome. One systematic review of randomized trials found ESWT for orthopedic conditions to be as effective statistically, if not more so, as placebo or alternative treatments in up to 88.5% of trials.²⁰⁹ Regarding lower limb tendinopathies, the authors of a systematic review reported low level evidence for ESWT efficacy, although a large proportion of studies showed a high risk of bias.²¹⁰ Based on these reviews, and numerous others, it appears that ESWT may have clinical utility for MTU dysfunction.

Tendon Needling

One way to stimulate healing for tendinopathy could be to create a new injury, facilitating a new inflammatory response. To this end, clinicians may consider tendon needling, also termed tendon fenestration or tenotomy. During tendon fenestration, a needle (usually ranging between 18 and 22-gauge) is inserted with ultrasound guidance directly to the pathological tendon, withdrawn slightly, redirected, and advanced into a different portion of the tendon; the process is repeated 20 to 30 times until the pathological tissue has been addressed.²¹¹ The manufactured tendon damage is meant to create localized bleeding, fibroblast proliferation, and new formation of collagen. Tendon needling can be used as a stand-alone treatment, or may be performed in conjunction with other injectable interventions (eg, PRP or prolotherapy).

The proposed mechanism of action appears clinically relevant and effective: in the presence of a failed healing response, create a new healing response to allow normal healing. In 2015, a systematic review found 4 studies evaluating the effectiveness of tendon needling alone compared to tendon needling with additional interventions. The authors found tendon needling for tendinopathy to be effective in improving pain and functional outcomes, and outcomes appeared to be improved when additional PRP injections were provided.²¹² Another more recent literature review examined the effects of high-volume image-guided injection and dry needling for Achilles tendinopathy. In the 4 case series reviewed, high-volume injections were effective in reducing pain in both the short and medium term, although results were better when dry needling was not included.²¹³ It should be noted that follow-up assessments for these reviews were limited to between immediate and 6 months. While the theoretical mechanism for healing appears logical, the lack of studies investigating long-term follow-up results should be considered a limitation in current research.

Caution is suggested with this intervention because of the unknown long-term effect of tendon sheath penetration and disruption. Inherent in tendon fenestration is a theoretical weakening of the tendon itself, and while short-term outcomes may be promising, the long-term effect (the possibility of weakening and subsequent tendon re-injury or rupture) is unknown.

Surgical Intervention

In the case of acute MTU rupture or where conservative options have failed and a patient continues to have MTU-related pain or disability, surgical intervention may be indicated. If surgery is a viable option, the patient needs to participate in the decision-making process and should be provided with available data to make an informed choice. Open communication throughout the process with orthopedic providers, rehabilitation experts, patients, their families, and their support systems will likely enhance short, medium, and long-term outcomes.

A brief targeted search of surgical techniques for MTU injury resulted in thousands of results (from PubMed alone!).

Superficially presenting the extensive possibilities would not do justice to the intricacies of operative options, and would not be able to address the abundant MTU injuries being treated by surgical methods. Generally, the goal of surgical intervention is to create an environment where the MTU has the capacity to function. When a tendon detaches from the bony insertion and complete tendinous or muscular rupture occurs, reattachment is typically the first priority to create a continuous muscle-tendon-bone interface to provide voluntary movement. After surgical repair, it is common to immobilize the MTU in a somewhat slackened position. This avoids excessive tensile strain on the healing structure or adaptive shortening, which could be more challenging to elongate as collagen and scar tissue matures. In cases of recalcitrant tendinopathy or chronic scarring of muscle tissue, debridement is usually preferred to remove pathological tissue. As with most surgeries, the lesser the pre-op impact of physical impairments at the BSF level, the better the prognosis. If at all possible, prolonged immobilization should be minimized to facilitate normalizing muscle performance and flexibility, tendon strength, and ultimately to optimize MTU tissue tolerance.

INCREASING MUSCLE AND

TENDON TOLERANCE

Building Tissue Capacity

Through an understanding of biomechanical principles that guide MTU performance, clinicians can identify how to safely enhance the quality of MTU tissues. To emphasize how to build tissue capacity, consider a quadriceps muscle complete rupture and surgical fixation. Evaluating baseline capacity would be the first step in increasing tissue tolerance, identifying where and to what extent dysfunction exists. Quadriceps muscle activation is expected to be impaired, and recovery of muscle performance typically would follow a phasic progression from static holds (isometric) to controlled contraction (concentric), and to controlled elongation (eccentric), incorporating functional activities as tolerated. Logically, tissue tolerance to isometric exercise would be expected prior to increasing tissue load through eccentric plyometric exercises. The speed of progression depends primarily on tissue healing timelines, tissue quality, patient tolerance, and clinician observation/determinations. To be able to progress strengthening, the patient should have the capacity to move, in which case tibiofemoral and patellofemoral joint motion and extensibility of the hamstrings, calf, and quadriceps muscles should be normalized.

To build the tissue capacity of an MTU, it is imperative to ensure that adjacent MTUs and joint segments are contributing appropriately to functional tasks. Consider a patient recovering from a quadriceps muscle repair, now trying to negotiate stairs. In this primarily sagittal plane task, unless hip abductors are functioning to maintain the pelvis and femur in the frontal plane, a dynamic valgus moment may occur at the knee. With knee valgus, an altered line of pull in the frontal plane put strain

on the quadriceps tendon, which may be excessive for a healing tissue. Additionally, given the altered line of pull and resultant compressive load on the patella, it is possible that secondary patellofemoral complaints may arise. Increasing neuromuscular control of proximal and distal segments may allow clinicians to avoid overloading a healing tissue and to gradually and safely build tissue capacity and tolerance.

Building tissue capacity also requires clear and frequent communication between the provider and patient to determine the expected level of function and necessary task performance. For a patient recovering from a ruptured Achilles tendon and hoping to return to basketball, the clinician needs at some point to incorporate return to sport training, including but not limited to increasing endurance, power, and multidirectional load transference. Even if impairment-based metrics are considered sufficient, the athlete may not have built enough capacity within the tissue to return to sport safely. Again, knowing the anatomic structure of the MTU may allow clinicians to safely load the tissue, understanding that functional recovery may occur well before complete tissue capacity is achieved, which may be many months or even a year after the injury.

Injury Prevention

To prevent all injuries associated with sport performance is unrealistic, and probably impossible, given the inability to control for every variable associated with activity. However, from a theoretical standpoint, many of the risk factors for developing MTU pathology are modifiable. For example, screening individuals pre-participation may allow targeted interventions that minimize the risk of an impairment that will contribute to the development of pathology.

Some authors have investigated the effectiveness of preventative programs that involve stretching. In the hamstring literature, for example, flexibility deficits of the hamstring and quadriceps muscle may predispose individuals to a greater likelihood of sustaining a strain. However, multiple studies have incorporated hamstring stretching in prevention studies, but did not find a reduction in the incidence of hamstring injuries.^{214,215} When expanding the question of the utility of stretching for injury risk reduction beyond hamstring injuries, the results are conflicting. Some studies have shown stretching may lower risk while others report no effect²¹⁶; however, variables such as study sample populations, comparison groups, and compliance should be considered when evaluating conclusions.

Muscle performance and force production impairments often correlate to injury as well. A number of studies have incorporated eccentric exercise in order to prevent injury. Eccentric exercise is a combination of active and passive tension, which creates a greater total tension capacity of a muscle group; it is possible that injury occurs when the tissue involved is unable to accept the total load applied. In soccer and running, hamstring strains often occur when running at maximal speed or during movements involving extreme hip flexion and knee extension.¹⁴³

It would therefore seem rational to build capacity and reduce injury risk for soccer players by enhancing eccentric control of the hamstrings. A recent systematic review with meta-analysis found that injury frequency was reduced in athletes who completed eccentric exercise programs compared to those who did not, and when compliance was better, so too were outcomes.²¹⁷

Similar cases could be made for injuries in other sports. With training errors as a common extrinsic risk factor, creating appropriate training programs and adapting as needed to avoid ramping up too quickly should reduce the risk of injury. If there is a mobility deficit within a joint, mobilizing the joint should allow typical motion, reducing the possibility of compensatory movement. However, while the theory is compelling, implementing these programs can be challenging because of the countless variables occurring during recreational or sport activity performance, the cost of designing and implementing programs, and the difficulty with compliance and outcome tracking using longitudinal data. Therefore, clinicians, trainers, coaches, physicians, and all others involved in a patient's care should be diligent about identifying and modifying risk factors as much as possible, but focus on adapting to patient needs throughout the duration of their care.

Supplementation

With the remarkable advances in sport science, nutritional supplementation has become a pervasive and lucrative industry. Nutritional imbalance can play a role in the development and persistence of disease, thus, optimizing one's diet should improve the capacity to heal and maintain function. Additionally, when considering options to improve performance, supplements can be used to boost MTU capacity and performance. However, excessive or inappropriate use of supplementation may have adverse effects on the MTU, of which clinicians, researchers, and educators should be aware.

One category of supplement that has garnered a great deal of attention, particularly in the athletic realm, is that of anabolic steroids. Individuals often choose to consume anabolic steroids to increase muscle mass, increase strength, decrease recovery time, and expedite injury healing, through a series of anti-catabolic interactions. However, a number of adverse effects are associated with multiple body systems, making the use of anabolic steroids potentially dangerous. This has prompted athletic and medical committees to issue statements warning of the effects, and in some cases to prohibit use. Examples of adverse effects include decreased reproductive capacity, liver damage, increased cholesterol levels and blood pressure, increased risk of MTU injury, infection, mood swings, aggressive behavior, depression, and addiction.²¹⁸ However, in some cases of MTU impairment, such as aging-related sarcopenia or chronic disease, muscle anabolic activity may benefit from supplemental enhancement. To this end, testosterone or growth hormone may be appropriate prescriptions.²¹⁹

Protein commonly is used in efforts to increase muscle mass and strength. An increased rate of protein re-synthesis occurs after resistance exercise. Additional protein ingestion during this time is thought to assist in enhancing lean body mass and muscle hypertrophy.²²⁰ While the daily recommended intake of protein for resistance athletes is nearly double that for sedentary individuals, increasing protein intake does not always correlate positively to muscle growth.²²¹

Creatine supplementation is common, attracting younger and younger users, and has been associated with increased lean tissue mass and muscle strength. Creatine is thought to increase adenosine triphosphate availability, which is required for short-duration high-intensity activity.²²² Based on the proposed mechanism and physiologic effects, creatine may be beneficial specifically for improving strength, power, and sprint performance during maximal effort. Recent systematic reviews with meta-analysis reported creatine supplementation had positive effects on upper extremity²²³ and lower extremity²²⁴ strength performance, and for older adults.²²⁵ While positive results exist for improving MTU performance, particularly for anaerobic-based activities, additional research on long term and possible adverse effects would be useful.

Caffeine may play a role in improving performance. Through the physiological mechanisms of increasing epinephrine and cortisol levels, glycogen sparing and adenosine receptor antagonism, caffeine ingestion has been associated with increased time to exhaustion and decreased recovery times for cycling, running, and swimming athletes, although similar performance enhancement was not seen for athletes participating in short-duration exercise.²²⁶ Excessive intake may have negative effects on the performance variables of mood, concentration, and alertness, while also potentially increasing heart rate and blood pressure.²²²

CONCLUSION

Human movement is a complex and intricate series of interactions of multiple body systems that allow us to perform our daily activities. Without a functioning muscle and tendon unit, our movement and functional capacity would be severely affected. To this end, this monograph is intended to highlight MTU anatomy and biomechanics, discuss pathophysiologic principles associated with MTU dysfunction, and summarize the available evidence related to the treatment and prevention of MTU pathology. The author hopes that the information provided will enable readers to better understand a patient's MTU capacity, the variables affecting MTU tissue tolerance, and will provide a starting point for improving functional levels and quality of life for persons with MTU pathology. It should not be forgotten, however, that while tissue level pathology can and should be treated when possible, many variables play into a patient's recovery. For example, an individual with fear of reinjury will likely have a poor prognosis unless psychologically informed care is provided²²⁷ and patients with sensitized nervous

systems in addition to their peripheral complaint may benefit from treatments directed at aberrant pain input and processing mechanisms.^{55,56,166}

One of the true skills of the physical therapy profession is applying the art of caring to the science of healing. Patient-centric individualized care using shared decision making can greatly improve a patient's life. The individualized care required also presents an inherent challenge to integrating high quality evidence into decision making, because systematic reviews and clinical practice guidelines do not always apply to every individual patient. In order to enhance muscle and tendon unit tissue tolerance, clinicians are expected to integrate their own expertise with the patient's values and best available evidence (when available) in optimizing care.

CASE STUDIES

The previous sections aimed to provide readers with available evidence on normal and abnormal MTUs, including evidence supporting current management options. To reinforce the previously described information, 4 patient cases are provided. The primary purpose of the cases is to offer the reader opportunities to place the available evidence related to MTU tissue tolerances into a clinical context.

Case Study 1: Postoperative Shoulder Pain and Functional Loss

The patient was a 67-year-old male presenting to physical therapy for initial evaluation, after undergoing an arthroscopic right rotator cuff repair 1 week prior for a massive full-thickness supraspinatus tear. He complained of right shoulder pain, weakness, and lack of function. He described his pain as a deep constant ache, 5/10 on average, 2/10 at best, 9/10 at worst. His pain was made worse when lying on the right side and using his arm. His symptoms felt better when he was resting his arm at his side, after taking medicine (ibuprofen 600mg), and when using ice. He had difficulty sleeping through the night because of discomfort. Symptoms were local to the shoulder, and he denied any numbness, tingling, or radiating pain. His medical history included hypercholesterolemia, uncontrolled diabetes mellitus type II, and degenerative disc disease in his cervical spine.

Upon examination, the patient demonstrated guarding of his right shoulder and limited willingness to move (or be moved). He reported a substantial fear that his arm would get worse with movement, and was scared of re-tearing his rotator cuff. His arm was in a sling, resting on his stomach. His left arm was within functional limits in ROM and strength. His right arm was warm to the touch, with appropriate scar healing and mobility. His passive ROM was 60° flexion, 40° abduction, 10° external rotation, and 50° internal rotation. He scored 90/100 on the QuickDASH. His goal was to be painfree and not need help or extra time to do daily tasks.

MTU tissue tolerance considerations

- The patient's past medical history contained two conditions that would slow the typical rate of tissue healing and could adversely affect the quality of the cuff repair (hypercholesterolemia, DM II).
- The patient's age could predispose the patient to a weaker tendon structure, reduced peak muscle strength, and type II fiber distribution.
- The patient was taking ibuprofen. Pain medication is expected immediately after rotator cuff repair; however, NSAIDs may play a role in the inhibition of expected inflammatory processes, potentially prolonging the recovery.
- Fear of movement and reinjury would possibly minimize the patient's active use of the arm, leading in turn to disuse atrophy or compensatory guarding and muscle imbalance.
- The position of immobilization (shoulder internal rotation) could preposition the cuff tendons in a shortened position, which might be associated with decreased long-term extensibility and tendon weakness.

Patient management priority considerations

- The patient's reported pain and ROM status is not uncommon and the aggravating activities were typical given the recent nature of surgical intervention. The patient was progressing as expected. However, local forms of pain management should replace NSAIDs when possible (eg, cold therapy).
- Frequently, immediate priorities with a muscle injury (including surgery) are to manage pain, prevent atrophy, and improve ROM. With surgical repair, although range must be improved, the strength of the graft is weakest for the first two months, and risk of re-tear is higher once pain is reduced and the patient feels slightly more functional. This patient needed explicit education regarding the typical progression of rotator cuff repairs, incorporating prolonged durations at early phases, given his general medical status and age. The overall prognosis was good, and the patient was made aware of this to alleviate some of his reduced willingness to move.
- Although early ROM progressions should be controlled, patients with shoulder pathology and diabetes mellitus tend to have stiffer shoulders and more pain at longer term follow-up, compared to those without diabetes mellitus. The patient should consistently move in available range, when deemed safe to do so.
- Submaximal isometrics should be incorporated after a couple weeks to improve MTU contractility and neuromuscular control and decrease pain.

Case Study 2: Chronic Elbow Pain

The patient was a 36-year-old male presenting to physical therapy with complaints of chronic lateral elbow pain of insidious onset nearly 3 years prior. Symptoms had been on and off during the last few years, but currently the symptoms seemed to be more consistent and functionally limiting. He had seen

a number of physical therapists and chiropractors in the past, but symptoms did not resolve. He said they gave him elbow strengthening and stretching exercises, did some passive muscle stretching, and used ice, heat and e-stim. He was a general contractor and needed functional use of his arm. He had to take off the prior week because of severe pain, which caused increased anxiety and stress. He stated his general health was good, although his blood pressure was higher than usual at his recent annual physical. He was trying to quit smoking cigarettes, and was down to 2-3 each day in the last month, from 1 pack a day for the past 2 years.

On examination, the patient had point tenderness at the common extensor tendon, pain with resisted wrist and third digit extension, and pain with passive wrist flexion. There was thickening of the tendon origin, compared to the uninvolved side. Pressure-pain thresholds were reduced at the involved and uninvolved tendons. Cervical and neurological screening was normal, and did not recreate any symptoms. He scored 79/100 on the Patient Rated Tennis Elbow Evaluation. His primary goal was to return to work without pain.

MTU tissue tolerance considerations

- A history of smoking is a risk factor for developing lateral epicondylalgia and negatively impacts the prognosis of recovery from MTU pathology.
- Pressure-pain thresholds were reduced at the uninvolved tendon, suggesting central pain processing might be impaired. A number of reports have linked lateral epicondylalgia to central sensitization. The patient's stress and anxiety also likely served to augment the nervous system.
- Degenerative changes at the common extensor tendon are not always correlated to symptoms; however, they are seen less frequently in a 36-year-old active male, suggesting that imaging might have relevance here.

Patient management priority considerations

- The patient should be informed of the deleterious effects of smoking on MTU health and repair capacity. The patient was reducing his intake, which should be commended; however, recovery might be protracted as a result of the patient's history.
- If central pain mechanisms are altered, addressing the peripheral problem alone may prove ineffective. Treating the tendon locally with exercise, mobilization with movement, and other relevant interventions would be important, but down-modulating the nervous system through aerobic exercise, pain education, etc. would also likely be helpful.
- It was difficult to say if the degenerative changes were relevant; however, the recurrent nature of the patient's symptoms suggested that his tendon load capacity was reduced. Exercise should progress to include eccentric activity, promoting increased endurance for his vocation and allowing increased load tolerance.

- Education related to the effectiveness of physical therapy for the condition should be considered throughout the course of care. The patient had been to various practitioners before, without achieving a preferred level of recovery, and had more anxiety and stress, which could be reduced with clear communication on the condition and prognosis.
- Given the patient's need to return to work sooner than later, additional adjunctive interventions to reduce short-term pain might be useful. Joint mobilization/manipulation of the cervical spine may aid in reducing pain sensitivity for patients with lateral epicondylalgia, and friction mobilization may also have a role. Prolotherapy has some supportive evidence, PRP evidence appears to be conflicting, and while corticosteroid injections produce short-term pain relief, the long-term outcomes are not good and should be avoided if possible.

Case Study 3: Acute Thigh Injury

The patient was a 17-year-old female senior soccer player referred by the athletic trainer of her high school. She said that during a game 3 days earlier, she was sprinting forward and felt an immediate sharp pain in the back of her right leg around the buttock. The pain made her fall to the ground and she had to be removed from the game during a stoppage in play. She had been using ice and a compression bandage consistently, and had been able to walk but with some pain. At rest she did not have any pain, but after sitting in class greater than 30 minutes, walking greater than 5 minutes, getting in or out of a car, or when putting on her pants she had about a 3/10 pain in her hamstring. At the end of the day she noticed a stronger ache (6-7/10). Her season had just begun, and she was hopeful of returning to play as soon as possible, since she was actively being recruited for Division I scholarships. Her team physician had scheduled her for an MRI later that week.

Upon examination, she demonstrated an antalgic gait with decreased knee flexion and shorter step length on the right. She performed a squat by shifting weight substantially to the left, and had decreased depth. Resisted hamstring testing of the left was strong and painfree, while the right was weak (3/5 MMT) and painful. Her knee ROM was normal but a straight leg raise (SLR) was limited to 45°, where she had some pain and displayed tissue resistance. During the SLR, she also complained of a tingling in her calf, which she had not noticed before. She had exceptional tenderness to palpation 3 inches distal to the ischial tuberosity, where ecchymosis and mild localized swelling was observed. She scored 42/80 on the Lower Extremity Functional Scale.

MTU tissue tolerance considerations

- The patient presentation was consistent with a hamstring strain. Determining the extent of injury is important, to determine which tissues need to be protected. Based on the British Athletics Muscle Injury Classification, this patient likely had a grade II (moderate) or III (extensive) injury. Her

injury was severe enough to immediately prevent her from continuing play, she had painful weakness of the hamstrings and guarding with testing and functional movement. An MRI could help confirm the condition.

- Her SLR was about half of what would be expected for a 17-year-old female, suggesting a muscle length impairment. She also had tingling, possibly related to sciatic nerve compression from local hemorrhage/edema.
- The patient sustained the injury 3 days earlier, and was in the acute inflammatory phase of healing. Local tissues should be protected and controlled reloading should not disrupt healing processes.
- Her age was a positive prognostic factor in returning to activity. Tissue adaptation and injury repair occur more readily in the younger population.

Patient management priority considerations

- This patient likely did not sustain a complete rupture, so conservative management would be preferred. She had the added pressure of returning to play because of possible college scholarship offers. However, the recurrence rate of hamstring injuries is high, and incomplete recovery could set up this athlete for failure long term.
- The initial goals for this patient would be to protect scar development by avoiding end range stretching, avoid atrophy by submaximal hamstring recruitment, and manage pain. Activities such as stationary cycling, bridges, submaximal isometrics, and functional gait retaining should be incorporated.
- Progression to phase II could occur after she has normal walking gait, is able to jog very slowly without pain, and has had painfree submaximal isometric hamstring testing. Progression to phase III would occur when she has full strength without pain during hamstring MMT and is able to jog forward and backward at a moderate intensity without pain. Return to sport criteria should include full strength with multiple hamstring MMTs, good hamstring to quadriceps ratio, full painfree ROM, and competence with sport-specific drills at or near full speed without symptoms.¹⁴³
- Advancement through the phasic recovery process should be patient/athlete specific. However, on the short end, hamstring injuries without additional complication or set-backs should typically take 2 months. Theoretically, the athlete might still have been in season; however, given the severity of the injury, recurrence rate, substantial load demand with sprinting and changing direction, she should be educated of the possibility that she could not return this season.

Case Study 4: Recurrent Anterior Knee Pain

The patient was a 20-year-old male presenting to physical therapy with complaints of left anterior knee pain which prevented him from participating in his college's intramural basketball league. He had pain on and off for the prior 6 years. He initially noticed the symptoms when he started to play basket-

ball for his high school team. His pain would be so bad that he would have to miss about 20% of his games each season, but the pain would reduce in the off-season. He had treatment in and out of season, but running and jumping consistently exacerbated the pain. He was becoming frustrated by the lack of long-term improvement. He did not have pain when he was not playing basketball or volleyball (less frequent participant), but loved the sport and wanted to continue playing. He also had pain going up or down stairs, squatting, and sitting for a 45-minute lecture. Previous treatments consisted of quadriceps muscle stretching, exercise on machines, squats slowly focusing on the down phase with one leg, transverse friction, noxious e-stim, orthotics, ice massage, and rest.

Upon examination, there was some redness and thickening of the left patellar tendon. Tenderness was present at the inferior pole of the patella, extending about 1 cm inferior. There was no tenderness at the tibial tuberosity or proximal to the tendon's origin. Walking gait was generally normal, although excessive pronation on the left was noticed from loading response through terminal stance. When performing a bilateral squat, the left heel came off the ground. During a single-leg squat, there was excessive calcaneal eversion and femoral adduction, and some pain was reproduced. During a single-leg decline squat, typical pain was reproduced at the inferior pole of the patella, and he was unable to perform a second repetition because of pain. A Thomas test was normal, as was an SLR and an Ober test. Joint assessment revealed hypomobility of the patellofemoral and talocrural joints. Diagnostic ultrasound of the involved tendon suggested focal areas of hypoechoogenicity and some fibril discontinuity. He scored 63/100 on the VISA-P.

MTU tissue tolerance considerations

- The patient was young and active, which typically is advantageous for tissue and functional recovery.
- A chronic history of similar tendon pain suggested intolerance to the functional demand of jumping. Patellar tendinopathy is commonly aggravated by strong tensile forces associated with jumping sports.
- The patient's repetitive symptom onset during basketball season and ultrasound changes suggested tendon dysrepair, if not degenerative tendinopathy.
- Joint mobility restrictions of the knee and ankle were present, although muscle length of biarticular muscles at the hip appeared to be normal. Reduced joint excursion at the ankle likely contributed to early heel rise and excessive pronation,

which will alter the kinetics and kinematics of tasks, particularly the moment arm and internal joint torque required. Reduced mobility of the patellofemoral joint may concentrate load on a smaller portion of the tendon, predisposing it to overuse, rather than allowing the entire tendon to disperse force.

- The patient had had a number of treatments, some appearing to be appropriate, but continued to have symptoms. It is likely that full capacity was not achieved in each case.

Patient management priority considerations

- This patient appeared to have a consistent aggravation of symptoms when regularly playing basketball. The demand from jumping was not being met by the capacity of the patient, so overload was consistently occurring, in this case at the patellar tendon. The priority should be to optimize load tolerance of the patellar tendon. To this end, evaluation of the entire biomechanical chain would assess possible compensatory movements or options to avoid overloading the tendon.
- In this case, joint restrictions at the ankle and knee might play a role in the patient's intolerance to jumping. Ankle dorsiflexion and knee flexion are required to allow for vertical propulsion, and if restrictions exist, it is possible that undue strain is localized to the patellar tendon in preparation for and during the jump. Joint mobilization/manipulation to the patellofemoral and talocrural joints could be helpful to optimize movement.
- On examination, dynamic activities caused an increase in symptom severity and irritability. Pain management should be a priority, which could likely be achieved from isometric holds (short or long duration). As pain begins to reduce, and hopefully patient frustration begins to reduce, phasic progressive loading should begin. Eccentric exercise may be helpful, but if it had been performed appropriately before without benefit, additional options might be relevant. In this case, HSR could be useful, given the equivalent clinical effectiveness to eccentrics for patellar tendinopathy, but also the added benefit of superior patient satisfaction in some cases.
- As pain reduces and functional activity capacity increases, this patient would benefit from sport-specific functional training, to include progressive hop drills, jumping, and jump landing training, etc. A program to maintain improvements should be performed when he is not participating in sports, and some training should occur prior to initiation of basketball participation as well.

REFERENCES

1. GBD 2016 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet.* 2017;390(10100):1211-1259. doi: S0140-6736(17)32154-2 [pii].
2. United States Bone and Joint Initiative. *The Burden of Musculoskeletal Diseases in the United States: Prevalence, Societal and Economic Cost.* 3rd ed. Rosemont, IL: United States Bone and Joint Initiative; 2014. Available at <http://www.boneandjointburden.org>.
3. Clarys JP, Martin AD, Drinkwater DT. Gross tissue weights in the human body by cadaver dissection. *Hum Biol.* 1984;56(3):459-473.
4. Frontera WR, Ochala J. Skeletal muscle: a brief review of structure and function. *Calcif Tissue Int.* 2015;96(3):183-195. doi: 10.1007/s00223-014-9915-y
5. Boron WF, Boulpaep EL. *Medical Physiology: A Cellular and Molecular Approach.* Philadelphia, PA: Saunders/Elsevier; 2009.
6. Kjaer M. Role of extracellular matrix in adaptation of tendon and skeletal muscle to mechanical loading. *Physiol Rev.* 2004;84(2):649-698. doi: 10.1152/physrev.00031.2003
7. Nordin M, Frankel VH, eds. *Basic Biomechanics of the Musculoskeletal System.* 4th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2012.
8. Knudsen AB, Larsen M, Mackey AL, et al. The human myotendinous junction: an ultrastructural and 3D analysis study. *Scand J Med Sci Sports.* 2015;25(1):e116-23. doi: 10.1111/sms.12221
9. Diaz-Vegas A, Eisner V, Jaimovich E. Skeletal muscle excitation-metabolism coupling. *Arch Biochem Biophys.* 2019;664:89-94. doi: S0003-9861(18)30881-6 [pii].
10. Neumann DA. *Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation.* 3rd ed. St. Louis, MO: Elsevier; 2017.
11. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle function. *J Physiol.* 2008;586(1):11-23. doi: jphysiol.2007.139477 [pii].
12. Woo SL, Debski RE, Zeminski J, Abramowitch SD, Saw SS, Fenwick JA. Injury and repair of ligaments and tendons. *Annu Rev Biomed Eng.* 2000;2:83-118. doi: 10.1146/annurev.bioeng.2.1.83.
13. Nicol C, Avela J, Komi PV. The stretch-shortening cycle : a model to study naturally occurring neuromuscular fatigue. *Sports Med.* 2006;36(11):977-999. doi: 10.2165/00007256-200636110-00004.
14. Komi PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *J Biomech.* 2000;33(10):1197-1206. doi: S0021-9290(00)00064-6.
15. Murphy DF, Connolly DA, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. *Br J Sports Med.* 2003;37(1):13-29. doi: 10.1136/bjsm.37.1.13.
16. Okita M, Yoshimura T, Nakano J, Motomura M, Eguchi K. Effects of reduced joint mobility on sarcomere length, collagen fibril arrangement in the endomysium, and hyaluronan in rat soleus muscle. *J Muscle Res Cell Motil.* 2004;25(2):159-166.
17. Hislop HJ, Avers D, Brown M. *Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination and Performance Testing.* 9th ed. St. Louis, MO: Elsevier; 2014.
18. Rainville J, Jouve C, Finno M, Limke J. Comparison of four tests of quadriceps strength in L3 or L4 radiculopathies. *Spine (Phila Pa 1976).* 2003;28(21):2466-2471. doi: 10.1097/01.BRS.0000090832.38227.98.
19. Wilk KE, Romaniello WT, Soscia SM, Arrigo CA, Andrews JR. The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL-reconstructed knee. *J Orthop Sports Phys Ther.* 1994;20(2):60-73. doi: 10.2519/jospt.1994.20.2.60 [doi].
20. Evans CJ, Chiou CF, Fitzgerald KA, et al. Development of a new patient-reported outcome measure in sarcopenia. *J Am Med Dir Assoc.* 2011;12(3):226-233. doi: 10.1016/j.jamda.2010.09.010.
21. Angst F, Schwyzer HK, Aeschlimann A, Simmen BR, Goldhahn J. Measures of adult shoulder function: Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH) and its short version (QuickDASH), Shoulder Pain and Disability Index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society standardized shoulder assessment form, Constant (Murley) Score (CS), Simple Shoulder Test (SST), Oxford Shoulder Score (OSS), Shoulder Disability Questionnaire (SDQ), and Western Ontario Shoulder Instability Index (WOSI). *Arthritis Care Res (Hoboken).* 2011;63 Suppl 11:S174-88. doi: 10.1002/acr.20630.
22. Mintken PE, Glynn P, Cleland JA. Psychometric properties of the shortened Disabilities of the Arm, Shoulder, and Hand questionnaire (QuickDASH) and Numeric Pain Rating Scale in patients with shoulder pain. *J Shoulder Elbow Surg.* 2009;18(6):920-926. doi: 10.1016/j.jse.2008.12.015.
23. Michener LA, McClure PW, Sennett BJ. American Shoulder and Elbow Surgeons Standardized Shoulder

- Assessment Form, patient self-report section: reliability, validity, and responsiveness. *J Shoulder Elbow Surg.* 2002;11(6):587-594. doi: 10.1067/mse.2002.127096.
24. Binkley JM, Stratford PW, Lott SA, Riddle DL. The Lower Extremity Functional Scale (LEFS): scale development, measurement properties, and clinical application. North American Orthopaedic Rehabilitation Research Network. *Phys Ther.* 1999;79(4):371-383.
 25. Martin RL, Irrgang JJ. A survey of self-reported outcome instruments for the foot and ankle. *J Orthop Sports Phys Ther.* 2007;37(2):72-84. doi: 10.2519/jospt.2007.2403.
 26. Robinson JM, Cook JL, Purdam C, et al. The VISA-A questionnaire: a valid and reliable index of the clinical severity of Achilles tendinopathy. *Br J Sports Med.* 2001;35(5):335-341. doi: 10.1136/bjsm.35.5.335.
 27. Visentini PJ, Khan KM, Cook JL, Kiss ZS, Harcourt PR, Wark JD. The VISA score: an index of severity of symptoms in patients with jumper's knee (patellar tendinosis). Victorian Institute of Sport Tendon Study Group. *J Sci Med Sport.* 1998;1(1):22-28. doi: S1440-2440(98)80005-4.
 28. Hernandez-Sanchez S, Hidalgo MD, Gomez A. Responsiveness of the VISA-P scale for patellar tendinopathy in athletes. *Br J Sports Med.* 2014;48(6):453-457. doi: 10.1136/bjsports-2012-091163.
 29. Fearon AM, Ganderton C, Scarvell JM, et al. Development and validation of a VISA tendinopathy questionnaire for greater trochanteric pain syndrome, the VI-SA-G. *Man Ther.* 2015;20(6):805-813. doi: 10.1016/j.math.2015.03.009.
 30. Cacchio A, De Paulis F, Maffulli N. Development and validation of a new visa questionnaire (VISA-H) for patients with proximal hamstring tendinopathy. *Br J Sports Med.* 2014;48(6):448-452. doi: 10.1136/bjsports-2012-091552.
 31. Vincent J, MacDermid JC. Patient-rated tennis elbow evaluation questionnaire. *J Physiother.* 2014;60(4):240. doi: 10.1016/j.jphys.2014.08.002.
 32. van der Worp H, van Ark M, Roerink S, Pepping GJ, van den Akker-Scheek I, Zwerver J. Risk factors for patellar tendinopathy: a systematic review of the literature. *Br J Sports Med.* 2011;45(5):446-452. doi: 10.1136/bjsm.2011.084079.
 33. Achilles pain, stiffness, and muscle power deficits: midportion Achilles tendinopathy revision 2018: using the evidence to guide physical therapist practice. *J Orthop Sports Phys Ther.* 2018;48(5):425-426. doi: 10.2519/jospt.2018.0505.
 34. Gaida JE, Ashe MC, Bass SL, Cook JL. Is adiposity an under-recognized risk factor for tendinopathy? A systematic review. *Arthritis Rheum.* 2009;61(6):840-849. doi: 10.1002/art.24518.
 35. Shiri R, Viikari-Juntura E, Varonen H, Heliovaara M. Prevalence and determinants of lateral and medi-al epicondylitis: a population study. *Am J Epidemiol.* 2006;164(11):1065-1074. doi: 10.1093/aje/kwj325.
 36. Green B, Pizzari T. Calf muscle strain injuries in sport: a systematic review of risk factors for injury. *Br J Sports Med.* 2017;51(16):1189-1194. doi: 10.1136/bjsports-2016-097177.
 37. Hagglund M, Walden M, Ekstrand J. Risk factors for lower extremity muscle injury in professional soccer: The UEFA Injury Study. *Am J Sports Med.* 2013;41(2):327-335. doi: 10.1177/0363546512470634.
 38. Sayampanathan AA, Andrew TH. Systematic review on risk factors of rotator cuff tears. *J Orthop Surg (Hong Kong).* 2017;25(1):2309499016684318. doi: 10.1177/2309499016684318.
 39. de Jonge S, van den Berg C, de Vos RJ, et al. Incidence of midportion Achilles tendinopathy in the general population. *Br J Sports Med.* 2011;45(13):1026-1028. doi: 10.1136/bjsports-2011-090342.
 40. Lantto I, Heikkilä J, Flinkkila T, Ohtonen P, Lepilahti J. Epidemiology of Achilles tendon ruptures: increasing incidence over a 33-year period. *Scand J Med Sci Sports.* 2015;25(1):e133-8. doi: 10.1111/sms.12253 .
 41. Emery CA, Meeuwisse WH, Powell JW. Groin and abdominal strain injuries in the National Hockey League. *Clin J Sport Med.* 1999;9(3):151-156.
 42. Ekstrand J, Hagglund M, Walden M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med.* 2011;39(6):1226-1232. doi: 10.1177/0363546510395879.
 43. Sanders TL Jr, Maradit Kremers H, Bryan AJ, Ransom JE, Smith J, Morrey BF. The epidemiology and health care burden of tennis elbow: a population-based study. *Am J Sports Med.* 2015;43(5):1066-1071. doi: 10.1177/0363546514568087.
 44. Zwerver J, Bredeweg SW, van den Akker-Scheek I. Prevalence of jumper's knee among nonelite athletes from different sports: a cross-sectional survey. *Am J Sports Med.* 2011;39(9):1984-1988. doi: 10.1177/0363546511413370.
 45. Eckard TG, Kerr ZY, Padua DA, Djoko A, Dompier TP. Epidemiology of quadriceps strains in National Collegiate Athletic Association athletes, 2009-2010 through 2014-2015. *J Athl Train.* 2017;52(5):474-481. doi: 10.4085/1062-6050-52.2.17.
 46. Aagaard KE, Abu-Zidan F, Lunsjo K. High incidence of acute full-thickness rotator cuff tears. *Acta Orthop.* 2015;86(5):558-562. doi: 10.3109/17453674.2015.1022433.
 47. Minagawa H, Yamamoto N, Abe H, et al. Prevalence of symptomatic and asymptomatic rotator cuff tears in the general population: from mass-screening in one village. *J Orthop.* 2013;10(1):8-12. doi: 10.1016/j.jor.2013.01.008.

48. Littlewood C, May S, Walters S. Epidemiology of rotator cuff tendinopathy: a systematic review. *Shoulder Elbow*. 2013;5(4):256-265.
49. Pollock N, James SL, Lee JC, Chakraverty R. British athletics muscle injury classification: a new grading system. *Br J Sports Med*. 2014;48(18):1347-1351. doi: 10.1136/bjsports-2013-093302.
50. Patel A, Chakraverty J, Pollock N, Chakraverty R, Suokas AK, James SL. British athletics muscle injury classification: a reliability study for a new grading system. *Clin Radiol*. 2015;70(12):1414-1420. doi: 10.1016/j.crad.2015.08.009.
51. Pollock N, Patel A, Chakraverty J, Suokas A, James SL, Chakraverty R. Time to return to full training is delayed and recurrence rate is higher in intratendinous ('c') acute hamstring injury in elite track and field athletes: clinical application of the British athletics muscle injury classification. *Br J Sports Med*. 2016;50(5):305-310. doi: 10.1136/bjsports-2015-094657.
52. Clancy WGJ. Tendon trauma and overuse injuries. In: Leadbetter WB, Buckwalter JA, Gordon SL, eds. *Sports-Induced Inflammation: Clinical and Basic Science Concepts*. Park Ridge, IL: American Academy of Orthopaedic Surgeons; 1990:609-618.
53. Cook JL, Purdam CR. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. *Br J Sports Med*. 2009;43(6):409-416. doi: 10.1136/bjsm.2008.051193.
54. Cook JL, Rio E, Purdam CR, Docking SI. Revisiting the continuum model of tendon pathology: what is its merit in clinical practice and research? *Br J Sports Med*. 2016;50(19):1187-1191. doi: 10.1136/bjsports-2015-095422.
55. Chimenti RL, Frey-Law LA, Sluka KA. A mechanism-based approach to physical therapist management of pain. *Phys Ther*. 2018;98(5):302-314. doi: 10.1093/ptj/pzy030.
56. Vardeh D, Mannion RJ, Woolf CJ. Toward a mechanism-based approach to pain diagnosis. *J Pain*. 2016;17(9 Suppl):T50-69. doi: 10.1016/j.jpain.2016.03.001 [doi].
57. Noten S, Struyf F, Lluch E, D'Hoore M, Van Looveren E, Meeus M. Central pain processing in patients with shoulder pain: a review of the literature. *Pain Pract*. 2017;17(2):267-280. doi: 10.1111/papr.12502.
58. Fernandez-Carnero J, Fernandez-de-Las-Penas C, de la Llave-Rincon AI, Ge HY, Arendt-Nielsen L. Widespread mechanical pain hypersensitivity as sign of central sensitization in unilateral epicondylalgia: a blinded, controlled study. *Clin J Pain*. 2009;25(7):555-561. doi: 10.1097/AJP.0b013e3181a68a040.
59. van Wilgen CP, Konopka KH, Keizer D, Zwerver J, Dekker R. Do patients with chronic patellar ten-
- dinopathy have an altered somatosensory profile? A quantitative sensory testing (QST) study. *Scand J Med Sci Sports*. 2013;23(2):149-155. doi: 10.1111/j.1600-0838.2011.01375.x.
60. Tompra N, van Dieen JH, Coppeters MW. Central pain processing is altered in people with Achilles tendinopathy. *Br J Sports Med*. 2016;50(16):1004-1007. doi: 10.1136/bjsports-2015-095476.
61. Plinsinga ML, van Wilgen CP, Brink MS, et al. Patellar and Achilles tendinopathies are predominantly peripheral pain states: a blinded case control study of somatosensory and psychological profiles. *Br J Sports Med*. 2018;52(5):284-291. doi: 10.1136/bjsports-2016-097163.
62. Mc Auliffe S, Whiteley R, Malliaras P, O'Sullivan K. Central sensitisation in different tendinopathies: are we comparing apples and oranges? *Br J Sports Med*. 2019;53(3):142-143. doi: 10.1136/bjsports-2017-098863.
63. Rio E, Moseley L, Purdam C, et al. The pain of tendinopathy: physiological or pathophysiological? *Sports Med*. 2014;44(1):9-23. doi: 10.1007/s40279-013-0096-z.
64. Neblett R, Cohen H, Choi Y, et al. The Central Sensitization Inventory (CSI): establishing clinically significant values for identifying central sensitivity syndromes in an outpatient chronic pain sample. *J Pain*. 2013;14(5):438-445. doi: 10.1016/j.jpain.2012.11.012.
65. Reeves ND, Narici MV, Maganaris CN. Myotendinous plasticity to ageing and resistance exercise in humans. *Exp Physiol*. 2006;91(3):483-498. doi: 10.1113/expphysiol.2005.032896.
66. Hunter SK, Thompson MW, Adams RD. Relationships among age-associated strength changes and physical activity level, limb dominance, and muscle group in women. *J Gerontol A Biol Sci Med Sci*. 2000;55(6):B264-73. doi: 10.1093/gerona/55.6.b264.
67. Hunter SK, Thompson MW, Ruell PA, et al. Human skeletal sarcoplasmic reticulum Ca²⁺ uptake and muscle function with aging and strength training. *J Appl Physiol (1985)*. 1999;86(6):1858-1865. doi: 10.1152/japplphysiol.1999.86.6.1858.
68. Svensson RB, Heinemeier KM, Couppe C, Kjaer M, Magnusson SP. Effect of aging and exercise on the tendon. *J Appl Physiol (1985)*. 2016;121(6):1237-1246. doi: 10.1152/japplphysiol.00328.2016.
69. Heinemeier KM, Schjerling P, Heinemeier J, Magnusson SP, Kjaer M. Lack of tissue renewal in human adult Achilles tendon is revealed by nuclear bomb (¹⁴C). *FASEB J*. 2013;27(5):2074-2079. doi: 10.1096/fj.12-225599.
70. Wall BT, Dirks ML, Snijders T, Senden JM, Dolmans J, van Loon LJ. Substantial skeletal muscle loss oc-

- curs during only 5 days of disuse. *Acta Physiol (Oxf)*. 2014;210(3):600-611. doi: 10.1111/apha.12190.
71. Jokl P, Konstadt S. The effect of limb immobilization on muscle function and protein composition. *Clin Orthop Relat Res*. 1983;(174):222-229.
 72. Rudrappa SS, Wilkinson DJ, Greenhaff PL, Smith K, Idris I, Atherton PJ. Human skeletal muscle disuse atrophy: effects on muscle protein synthesis, breakdown, and insulin resistance-a qualitative review. *Front Physiol*. 2016;7:361. doi: 10.3389/fphys.2016.00361.
 73. Kannus P, Jozsa L, Natri A, Jarvinen M. Effects of training, immobilization and remobilization on tendons. *Scand J Med Sci Sports*. 1997;7(2):67-71.
 74. Palmes D, Spiegel HU, Schneider TO, et al. Achilles tendon healing: long-term biomechanical effects of postoperative mobilization and immobilization in a new mouse model. *J Orthop Res*. 2002;20(5):939-946. doi: 10.1016/S0736-0266(02)00032-3.
 75. Kannus P, Jozsa L, Kvist M, Lehto M, Jarvinen M. The effect of immobilization on myotendinous junction: an ultrastructural, histochemical and immunohistochemical study. *Acta Physiol Scand*. 1992;144(3):387-394. doi: 10.1111/j.1748-1716.1992.tb09309.x.
 76. Lui PPY. Tendinopathy in diabetes mellitus patients-epidemiology, pathogenesis, and management. *Scand J Med Sci Sports*. 2017;27(8):776-787. doi: 10.1111/sms.12824.
 77. Batista F, Nery C, Pinzur M, et al. Achilles tendinopathy in diabetes mellitus. *Foot Ankle Int*. 2008;29(5):498-501. doi: 10.3113/FAI.2008.0498.
 78. de Jonge S, Rozenberg R, Vieyra B, et al. Achilles tendons in people with type 2 diabetes show mildly compromised structure: an ultrasound tissue characterisation study. *Br J Sports Med*. 2015;49(15):995-999. doi: 10.1136/bjsports-2014-093696.
 79. Siu KK, Zheng LB, Ko JY, et al. Increased interleukin 1beta levels in the subacromial fluid in diabetic patients with rotator cuff lesions compared with nondiabetic patients. *J Shoulder Elbow Surg*. 2013;22(11):1547-1551. doi: 10.1016/j.jse.2013.01.011.
 80. Moren-Hybinette I, Moritz U, Schersten B. The clinical picture of the painful diabetic shoulder--natural history, social consequences and analysis of concomitant hand syndrome. *Acta Med Scand*. 1987;221(1):73-82.
 81. Franceschi F, Papalia R, Paciotti M, et al. Obesity as a risk factor for tendinopathy: a systematic review. *Int J Endocrinol*. 2014;2014:670262. doi: 10.1155/2014/670262
 82. Abate M. How obesity modifies tendons (implications for athletic activities). *Muscles Ligaments Tendons J*. 2014;4(3):298-302.
 83. Rodriguez-Hernandez H, Simental-Mendia LE, Rodriguez-Ramirez G, Reyes-Romero MA. Obesity and inflammation: epidemiology, risk factors, and markers of inflammation. *Int J Endocrinol*. 2013;2013:678159. doi: 10.1155/2013/678159.
 84. Scott A, Zwerver J, Grewal N, et al. Lipids, adiposity and tendinopathy: is there a mechanistic link? Critical review. *Br J Sports Med*. 2015;49(15):984-988. doi: 10.1136/bjsports-2014-093989.
 85. Kiortsis DN, Argyropoulou MI, Xydis V, Tsouli SG, Elisaf MS. Correlation of Achilles tendon thickness evaluated by ultrasonography with carotid intima-media thickness in patients with familial hypercholesterolemia. *Atherosclerosis*. 2006;186(1):228-229. doi: 10.1016/j.atherosclerosis.2006.02.002.
 86. Ozgurtas T, Yildiz C, Serdar M, Atesalp S, Kutluay T. Is high concentration of serum lipids a risk factor for Achilles tendon rupture? *Clin Chim Acta*. 2003;331(1-2):25-28. doi: 10.1016/s0009-8981(03)00075-5.
 87. Tsouli SG, Kiortsis DN, Argyropoulou MI, Mikhailelidis DP, Elisaf MS. Pathogenesis, detection and treatment of Achilles tendon xanthomas. *Eur J Clin Invest*. 2005;35(4):236-244. doi: 10.1111/j.1365-2362.2005.01484.x.
 88. Ronnemaa T, Juva K, Kulonen E. Effect of hyperlipidemic rat serum on the synthesis of collagen by chick embryo fibroblasts. *Atherosclerosis*. 1975;21(3):315-324. doi: 10.1016/0021-9150(75)90045-3.
 89. Beason DP, Abboud JA, Kuntz AF, Bassora R, Soslowsky LJ. Cumulative effects of hypercholesterolemia on tendon biomechanics in a mouse model. *J Orthop Res*. 2011;29(3):380-383. doi: 10.1002/jor.21255.
 90. Heinemeier KM, Ohlenschlaeger TF, Mikkelsen UR, et al. Effects of anti-inflammatory (NSAID) treatment on human tendinopathic tissue. *J Appl Physiol (1985)*. 2017;123(5):1397-1405. doi: 10.1152/japplphysiol.00281.2017.
 91. Bittermann A, Gao S, Rezvani S, et al. Oral ibuprofen interferes with cellular healing responses in a murine model of Achilles tendinopathy. *J Musculoskelet Disord Treat*. 2018;4(2). doi:10.23937/2572-3243.1510049. Epub 2018 May 21.
 92. Almekinders LC. Anti-inflammatory treatment of muscular injuries in sport. An update of recent studies. *Sports Med*. 1999;28(6):383-388. doi: 10.2165/00007256-199928060-00001.
 93. Dideriksen K, Boesen AP, Reitelseder S, et al. Tendon collagen synthesis declines with immobilization in elderly humans: no effect of anti-inflammatory medication. *J Appl Physiol (1985)*. 2017;122(2):273-282. doi: 10.1152/japplphysiol.00809.2015.
 94. Abate M, Salini V, Schiavone C, Andia I. Clinical benefits and drawbacks of local corticosteroids injections in tendinopathies. *Expert Opin Drug Saf*. 2017;16(3):341-349. doi: 10.1080/14740338.2017.1276561.

95. Wilton LV, Pearce GL, Mann RD. A comparison of ciprofloxacin, norfloxacin, ofloxacin, azithromycin and cefixime examined by observational cohort studies. *Br J Clin Pharmacol.* 1996;41(4):277-284. doi: 10.1046/j.1365-2125.1996.03013.x.
96. Khaliq Y, Zhanell GG. Fluoroquinolone-associated tendinopathy: a critical review of the literature. *Clin Infect Dis.* 2003;36(11):1404-1410. doi: 10.1086/375078.
97. Corps AN, Curry VA, Harrall RL, Dutt D, Hazleman BL, Riley GP. Ciprofloxacin reduces the stimulation of prostaglandin E(2) output by interleukin-1beta in human tendon-derived cells. *Rheumatology (Oxford).* 2003;42(11):1306-1310. doi: 10.1093/rheumatology/keg372.
98. Lewis T, Cook J. Fluoroquinolones and tendinopathy: a guide for athletes and sports clinicians and a systematic review of the literature. *J Athl Train.* 2014;49(3):422-427. doi: 10.4085/1062-6050-49.2.09.
99. Marie I, Delafenetre H, Massy N, Thuillez C, Noblet C, Network of the French Pharmacovigilance Centers. Tendinous disorders attributed to statins: a study on ninety-six spontaneous reports in the period 1990-2005 and review of the literature. *Arthritis Rheum.* 2008;59(3):367-372. doi: 10.1002/art.23309.
100. Deren ME, Klinge SA, Mukand NH, Mukand JA. Tendinopathy and tendon rupture associated with statins. *JBJS Rev.* 2016;4(5):10.2106/JBJS.RVW.15.00072. doi: 10.2106/JBJS.RVW.15.00072.
101. Kuzma-Kuzniarska M, Cornell HR, Moneke MC, Carr AJ, Hulley PA. Lovastatin-mediated changes in human tendon cells. *J Cell Physiol.* 2015;230(10):2543-2551. doi: 10.1002/jcp.25010.
102. Parker L, Nazarian LN, Carrino JA, et al. Musculoskeletal imaging: Medicare use, costs, and potential for cost substitution. *J Am Coll Radiol.* 2008;5(3):182-188. doi: 10.1016/j.jacr.2007.07.016.
103. Nofsinger C, Konin JG. Diagnostic ultrasound in sports medicine: current concepts and advances. *Sports Med Arthrosc Rev.* 2009;17(1):25-30. doi: 10.1097/JSA.0b013e3181982add.
104. Milosavljevic J, Elvin A, Rahme H. Ultrasonography of the rotator cuff: a comparison with arthroscopy in one-hundred-and-ninety consecutive cases. *Acta Radiol.* 2005;46(8):858-865.
105. Warden SJ, Kiss ZS, Malara FA, Ooi AB, Cook JL, Crossley KM. Comparative accuracy of magnetic resonance imaging and ultrasonography in confirming clinically diagnosed patellar tendinopathy. *Am J Sports Med.* 2007;35(3):427-436. doi: 10.1177/0363546506294858.
106. McAuliffe S, McCreesh K, Culloty F, Purtill H, O'Sullivan K. Can ultrasound imaging predict the development of Achilles and patellar tendinopathy? A systematic review and meta-analysis. *Br J Sports Med.* 2016;50(24):1516-1523. doi: 10.1136/bjsports-2016-096288.
107. De Jonge S, Warnaars JL, De Vos RJ, et al. Relationship between neovascularization and clinical severity in Achilles tendinopathy in 556 paired measurements. *Scand J Med Sci Sports.* 2014;24(5):773-778. doi: 10.1111/sms.12072.
108. Magee T, Williams D. 3.0-T MRI of the supraspinatus tendon. *AJR Am J Roentgenol.* 2006;187(4):881-886. doi: 10.2214/AJR.05.1047.
109. Weinreb JH, Sheth C, Apostolakos J, et al. Tendon structure, disease, and imaging. *Muscles Ligaments Tendons J.* 2014;4(1):66-73.
110. Hodgson RJ, O'Connor PJ, Grainger AJ. Tendon and ligament imaging. *Br J Radiol.* 2012;85(1016):1157-1172. doi: 10.1259/bjr/34786470.
111. Khan KM, Forster BB, Robinson J, et al. Are ultrasound and magnetic resonance imaging of value in assessment of Achilles tendon disorders? A two year prospective study. *Br J Sports Med.* 2003;37(2):149-153. doi: 10.1136/bjsm.37.2.149.
112. Sher JS, Uribe JW, Posada A, Murphy BJ, Zlatkin MB. Abnormal findings on magnetic resonance images of asymptomatic shoulders. *J Bone Joint Surg Am.* 1995;77(1):10-15. doi: 10.2106/00004623-199501000-00002.
113. Gurney AB, Mermier C, LaPlante M, et al. Shoulder electromyography measurements during activities of daily living and routine rehabilitation exercises. *J Orthop Sports Phys Ther.* 2016;46(5):375-383. doi: 10.2519/jospt.2016.6090.
114. Distefano LJ, Blackburn JT, Marshall SW, Padua DA. Gluteal muscle activation during common therapeutic exercises. *J Orthop Sports Phys Ther.* 2009;39(7):532-540. doi: 10.2519/jospt.2009.2796.
115. Michet CJ, Matteson EL. Polymyalgia rheumatica. *BMJ.* 2008;336(7647):765-769. doi: 10.1136/bmj.39514.653588.80.
116. Schmidt J. Current classification and management of inflammatory myopathies. *J Neuromuscul Dis.* 2018;5(2):109-129. doi: 10.3233/JND-180308.
117. Constantinides VC, Papahatzaki MM, Papadimas GK, et al. Diagnostic accuracy of muscle biopsy and electromyography in 123 patients with neuromuscular disorders. *In Vivo.* 2018;32(6):1647-1652. doi: 10.21873/inivo.11427.
118. Joyce NC, Oskarsson B, Jin LW. Muscle biopsy evaluation in neuromuscular disorders. *Phys Med Rehabil Clin N Am.* 2012;23(3):609-631. doi: 10.1016/j.pmr.2012.06.006.
119. Dunn SL, Olmedo ML. Mechanotransduction: relevance to physical therapist practice-understanding our

- ability to affect genetic expression through mechanical forces. *Phys Ther.* 2016;96(5):712-721. doi: 10.2522/pjt.20150073.
120. Khan KM, Scott A. Mechanotherapy: How physical therapists' prescription of exercise promotes tissue repair. *Br J Sports Med.* 2009;43(4):247-252. doi: 10.1136/bjsm.2008.054239.
 121. Jenkins J, Beazell J. Flexibility for runners. *Clin Sports Med.* 2010;29(3):365-377. doi: 10.1016/j.csm.2010.03.004.
 122. Guissard N, Duchateau J. Neural aspects of muscle stretching. *Exerc Sport Sci Rev.* 2006;34(4):154-158. doi: 10.1249/01.jes.0000240023.30373.eb.
 123. Page P. Current concepts in muscle stretching for exercise and rehabilitation. *Int J Sports Phys Ther.* 2012;7(1):109-119.
 124. Freitas SR, Mendes B, Le Sant G, Andrade RJ, Nordez A, Milanovic Z. Can chronic stretching change the muscle-tendon mechanical properties? A review. *Scand J Med Sci Sports.* 2018;28(3):794-806. doi: 10.1111/sms.12957.
 125. Konrad A, Stafilidis S, Tilp M. Effects of acute static, ballistic, and PNF stretching exercise on the muscle and tendon tissue properties. *Scand J Med Sci Sports.* 2017;27(10):1070-1080. doi: 10.1111/sms.12725.
 126. Opplert J, Babault N. Acute effects of dynamic stretching on muscle flexibility and performance: an analysis of the current literature. *Sports Med.* 2018;48(2):299-325. doi: 10.1007/s40279-017-0797-9.
 127. Chimenti RL, Bucklin M, Kelly M, et al. Insertional Achilles tendinopathy associated with altered transverse compressive and axial tensile strain during ankle dorsiflexion. *J Orthop Res.* 2017;35(4):910-915. doi: 10.1002/jor.23338.
 128. Hart JM, Pietrosimone B, Hertel J, Ingersoll CD. Quadriceps activation following knee injuries: a systematic review. *J Athl Train.* 2010;45(1):87-97. doi: 10.4085/1062-6050-45.1.87.
 129. Naugle KM, Fillingim RB, Riley JL 3rd. A meta-analytic review of the hypoalgesic effects of exercise. *J Pain.* 2012;13(12):1139-1150. doi: 10.1016/j.jpain.2012.09.006.
 130. Rio E, Kidgell D, Purdam C, et al. Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. *Br J Sports Med.* 2015;49(19):1277-1283. doi: 10.1136/bjsports-2014-094386.
 131. Pearson SJ, Stadler S, Menz H, et al. Immediate and short-term effects of short- and long-duration isometric contractions in patellar tendinopathy. *Clin J Sport Med.* 2018. doi: 10.1097/JSM.0000000000000625.
 132. Lim HY, Wong SH. Effects of isometric, eccentric, or heavy slow resistance exercises on pain and function in individuals with patellar tendinopathy: a systemati-
 - ic review. *Physiother Res Int.* 2018;23(4):e1721. doi: 10.1002/pri.1721.
 133. Rio E, van Ark M, Docking S, et al. Isometric contractions are more analgesic than isotonic contractions for patellar tendon pain: an in-season randomized clinical trial. *Clin J Sport Med.* 2017;27(3):253-259. doi: 10.1097/JSM.0000000000000364.
 134. Alfredson H, Pietila T, Jonsson P, Lorentzon R. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. *Am J Sports Med.* 1998;26(3):360-366. doi: 10.1177/03635465980260030301.
 135. Jayaseelan DJ, Mischke JJ, Strazzulla RL. Eccentric exercise for Achilles tendinopathy: a narrative review and clinical decision-making considerations. *J Funct Morphol Kinesiol.* 2019;4(2):34. doi: 10.3390/jfmk4020034.
 136. Ohberg L, Lorentzon R, Alfredson H. Eccentric training in patients with chronic Achilles tendinosis: normalised tendon structure and decreased thickness at follow up. *Br J Sports Med.* 2004;38(1):8-11; discussion 11. doi: 10.1136/bjsm.2001.000284.
 137. Ohberg L, Alfredson H. Effects on neovascularisation behind the good results with eccentric training in chronic mid-portion Achilles tendinosis? *Knee Surg Sports Traumatol Arthrosc.* 2004;12(5):465-470. doi: 10.1007/s00167-004-0494-8.
 138. Drew BT, Smith TO, Littlewood C, Sturrock B. Do structural changes (eg, collagen/matrix) explain the response to therapeutic exercises in tendinopathy: a systematic review. *Br J Sports Med.* 2014;48(12):966-972. doi: 10.1136/bjsports-2012-091285.
 139. Ortega-Castillo M, Medina-Porquieres I. Effectiveness of the eccentric exercise therapy in physically active adults with symptomatic shoulder impingement or lateral epicondylar tendinopathy: a systematic review. *J Sci Med Sport.* 2016;19(6):438-453. doi: 10.1016/j.jsams.2015.06.007.
 140. Frizziero A, Vittadini F, Fusco A, Giombini A, Masiere S. Efficacy of eccentric exercise in lower limb tendinopathies in athletes. *J Sports Med Phys Fitness.* 2016;56(11):1352-1358. doi: R40Y9999N00A150196.
 141. Jonsson P, Alfredson H, Sunding K, Fahlstrom M, Cook J. New regimen for eccentric calf-muscle training in patients with chronic insertional Achilles tendinopathy: results of a pilot study. *Br J Sports Med.* 2008;42(9):746-749. doi: 10.1136/bjsm.2007.039545.
 142. Lorenz D, Reiman M. The role and implementation of eccentric training in athletic rehabilitation: tendinopathy, hamstring strains, and ACL reconstruction. *Int J Sports Phys Ther.* 2011;6(1):27-44.
 143. Heiderscheit BC, Sherry MA, Silder A, Chumanov ES, Thelen DG. Hamstring strain injuries: recommendations for diagnosis, rehabilitation, and injury prevention. *J Or-*

- thop Sports Phys Ther.* 2010;40(2):67-81. doi: 10.2519/jospt.2010.3047.
144. Kongsgaard M, Qvortrup K, Larsen J, et al. Fibril morphology and tendon mechanical properties in patellar tendinopathy: effects of heavy slow resistance training. *Am J Sports Med.* 2010;38(4):749-756. doi: 10.1177/0363546509350915.
145. Kongsgaard M, Kovanen V, Aagaard P, et al. Cortico-steroid injections, eccentric decline squat training and heavy slow resistance training in patellar tendinopathy. *Scand J Med Sci Sports.* 2009;19(6):790-802. doi: 10.1111/j.1600-0838.2009.00949.x.
146. Beyer R, Kongsgaard M, Hougs Kjaer B, Ohlenschlaeger T, Kjaer M, Magnusson SP. Heavy slow resistance versus eccentric training as treatment for Achilles tendinopathy: a randomized controlled trial. *Am J Sports Med.* 2015;43(7):1704-1711. doi: 10.1177/0363546515584760.
147. Ingwersen KG, Jensen SL, Sorensen L, et al. Three months of progressive high-load versus traditional low-load strength training among patients with rotator cuff tendinopathy: primary results from the double-blind randomized controlled RoCTEx trial. *Orthop J Sports Med.* 2017;5(8):2325967117723292. doi: 10.1177/2325967117723292.
148. Bialosky JE, Bishop MD, Price DD, Robinson ME, George SZ. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. *Man Ther.* 2009;14(5):531-538. doi: 10.1016/j.math.2008.09.001.
149. Vigotsky AD, Bruhns RP. The role of descending modulation in manual therapy and its analgesic implications: a narrative review. *Pain Res Treat.* 2015;2015:292805. doi: 10.1155/2015/292805.
150. Coronado RA, Gay CW, Bialosky JE, Carnaby GD, Bishop MD, George SZ. Changes in pain sensitivity following spinal manipulation: a systematic review and meta-analysis. *J Electromyogr Kinesiol.* 2012;22(5):752-767. doi: 10.1016/j.jelekin.2011.12.013.
151. Courtney CA, Steffen AD, Fernandez-de-Las-Penas C, Kim J, Chmell SJ. Joint mobilization enhances mechanisms of conditioned pain modulation in individuals with osteoarthritis of the knee. *J Orthop Sports Phys Ther.* 2016;1-30. doi: 10.2519/jospt.2016.6259.
152. Weerapong P, Hume PA, Kolt GS. The mechanisms of massage and effects on performance, muscle recovery and injury prevention. *Sports Med.* 2005;35(3):235-256. doi: 10.2165/00007256-200535030-00004.
153. Barnes MF. The basic science of myofascial release: morphologic change in connective tissue. *J Bodywork Movement Ther.* 1997;1(4):231-238.
154. Sharman MJ, Cresswell AG, Riek S. Proprioceptive neuromuscular facilitation stretching: mechanisms and clinical implications. *Sports Med.* 2006;36(11):929-939. doi: 10.2165/00007256-200636110-00002.
155. Godes JJ, Mattson-Bell M, Thorpe D, Shah D. The immediate effects of soft tissue mobilization with proprioceptive neuromuscular facilitation on glenohumeral external rotation and overhead reach. *J Orthop Sports Phys Ther.* 2003;33(12):713-718. doi: 10.2519/jospt.2003.33.12.713.
156. Maddigan ME, Peach AA, Behm DG. A comparison of assisted and unassisted proprioceptive neuromuscular facilitation techniques and static stretching. *J Strength Cond Res.* 2012;26(5):1238-1244. doi: 10.1519/JSC.0b013e3182510611.
157. Chamberlain GJ. Cyriax's friction massage: a review. *J Orthop Sports Phys Ther.* 1982;4(1):16-22. doi: 10.2519/jospt.1982.4.1.16.
158. Joseph MF, Taft K, Moskwa M, Denegar CR. Deep friction massage to treat tendinopathy: a systematic review of a classic treatment in the face of a new paradigm of understanding. *J Sport Rehabil.* 2012;21(4):343-353. doi: 10.1123/jsr.21.4.343.
159. Blackwood J, Ghazi F. Can the addition of transverse friction massage to an exercise programme in treatment of infrapatellar tendinopathy reduce pain and improve function? A pilot study. *Int Musculoskelet Med.* 2012;34(3):108-114. doi: 10.1179/1753615412Y.0000000005.
160. Stasinopoulos D, Stasinopoulos I. Comparison of effects of exercise programme, pulsed ultrasound and transverse friction in the treatment of chronic patellar tendinopathy. *Clin Rehabil.* 2004;18(4):347-352. doi: 10.1191/0269215504cr757oa.
161. Vicenzino B, Cleland JA, Bisset L. Joint manipulation in the management of lateral epicondylalgia: a clinical commentary. *J Man Manip Ther.* 2007;15(1):50-56. doi: 10.1179/106698107791090132.
162. Herd CR, Meserve BB. A systematic review of the effectiveness of manipulative therapy in treating lateral epicondylalgia. *J Man Manip Ther.* 2008;16(4):225-237. doi: 10.1179/106698108790818288.
163. Desjardins-Charbonneau A, Roy JS, Dionne CE, Fremont P, MacDermid JC, Desmeules F. The efficacy of manual therapy for rotator cuff tendinopathy: a systematic review and meta-analysis. *J Orthop Sports Phys Ther.* 2015;45(5):330-350. doi: 10.2519/jospt.2015.5455.
164. Mischke JJ, Emerson Kavchak AJ, Courtney CA. Effect of sternoclavicular joint mobilization on pain and function in a patient with massive supraspinatus tear. *Physiother Theory Pract.* 2016;32(2):153-158. doi: 10.3109/09593985.2015.1114691.
165. Jayaseelan DJ, Kecman M, Alcorn D, Sault JD. Manual therapy and eccentric exercise in the management of Achilles tendinopathy. *J*

- Man Manip Ther.* 2017;25(2):106-114. doi: 10.1080/10669817.2016.1183289.
166. Jayaseelan DJ, Weber MJ, Jonely H. Potential nervous system sensitization in patients with persistent lower extremity tendinopathies: 3 case reports. *J Orthop Sports Phys Ther.* 2019;49(4):272-279. doi: 10.2519/jospt.2019.8600.
 167. Jayaseelan DJ, Post AA, Mischke JJ, Sault JD. Joint mobilization in the management of persistent insertional Achilles tendinopathy: a case report. *Int J Sports Phys Ther.* 2017;12(1):133-143.
 168. Hensley CP, Kavchak AJ. Novel use of a manual therapy technique and management of a patient with peroneal tendinopathy: a case report. *Man Ther.* 2012;17(1):84-88. doi: 10.1016/j.math.2011.04.004.
 169. Kim KM, Croy T, Hertel J, Saliba S. Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. *J Orthop Sports Phys Ther.* 2010;40(7):383-391. doi: 10.2519/jospt.2010.3184.
 170. Glaviano NR, Saliba S. Can the use of neuromuscular electrical stimulation be improved to optimize quadriceps strengthening? *Sports Health.* 2016;8(1):79-85. doi: 10.1177/1941738115618174.
 171. Jones S, Man WD, Gao W, Higginson IJ, Wilcock A, Maddocks M. Neuromuscular electrical stimulation for muscle weakness in adults with advanced disease. *Cochrane Database Syst Rev.* 2016;10:CD009419. doi: 10.1002/14651858.CD009419.pub3.
 172. Robertson VJ, Baker KG. A review of therapeutic ultrasound: effectiveness studies. *Phys Ther.* 2001;81(7):1339-1350. doi: 10.1093/ptj/81.7.1339.
 173. Desmeules F, Boudreault J, Roy JS, Dionne C, Fremont P, MacDermid JC. The efficacy of therapeutic ultrasound for rotator cuff tendinopathy: a systematic review and meta-analysis. *Phys Ther Sport.* 2015;16(3):276-284. doi: 10.1016/j.ptsp.2014.09.004.
 174. Wilkin LD, Merrick MA, Kirby TE, Devor ST. Influence of therapeutic ultrasound on skeletal muscle regeneration following blunt contusion. *Int J Sports Med.* 2004;25(1):73-77. doi: 10.1055/s-2003-45234.
 175. Markert CD, Merrick MA, Kirby TE, Devor ST. Nonthermal ultrasound and exercise in skeletal muscle regeneration. *Arch Phys Med Rehabil.* 2005;86(7):1304-1310. doi: 10.1016/j.apmr.2004.12.037.
 176. Tumilty S, Munn J, McDonough S, Hurley DA, Basford JR, Baxter GD. Low level laser treatment of tendinopathy: a systematic review with meta-analysis. *Photomed Laser Surg.* 2010;28(1):3-16. doi: 10.1089/pho.2008.2470.
 177. Haslerud S, Magnussen LH, Joensen J, Lopes-Martins RA, Bjordal JM. The efficacy of low-level laser therapy for shoulder tendinopathy: a systematic review and meta-analysis of randomized controlled trials. *Physiother Res Int.* 2015;20(2):108-125. doi: 10.1002/pri.1606.
 178. Martin RL, Chimenti R, Cuddeford T, et al. Achilles pain, stiffness, and muscle power deficits: midportion Achilles tendinopathy revision 2018. *J Orthop Sports Phys Ther.* 2018;48(5):A1-A38. doi: 10.2519/jospt.2018.0302.
 179. Alves AN, Fernandes KP, Deana AM, Bussadori SK, Mesquita-Ferrari RA. Effects of low-level laser therapy on skeletal muscle repair: a systematic review. *Am J Phys Med Rehabil.* 2014;93(12):1073-1085. doi: 10.1097/PHM.0000000000000158.
 180. Dommerholt J. Dry needling - peripheral and central considerations. *J Man Manip Ther.* 2011;19(4):223-227. doi: 10.1179/106698111X13129729552065.
 181. Donnelly J. *Travell, Simons & Simons' Myofascial Pain and Dysfunction: The Trigger Point Manual*. Lippincott Williams & Wilkins; 2018.
 182. Gattie E, Cleland JA, Snodgrass S. The effectiveness of trigger point dry needling for musculoskeletal conditions by physical therapists: a systematic review and meta-analysis. *J Orthop Sports Phys Ther.* 2017;47(3):133-149. doi: 10.2519/jospt.2017.7096.
 183. Morihisa R, Eskew J, McNamara A, Young J. Dry needling in subjects with muscular trigger points in the lower quarter: a systematic review. *Int J Sports Phys Ther.* 2016;11(1):1-14.
 184. Hall ML, Mackie AC, Ribeiro DC. Effects of dry needling trigger point therapy in the shoulder region on patients with upper extremity pain and dysfunction: a systematic review with meta-analysis. *Physiotherapy.* 2018;104(2):167-177. doi: 10.1016/j.physio.2017.08.001.
 185. Perez-Palomares S, Olivan-Blazquez B, Perez-Palomares A, et al. Contribution of dry needling to individualized physical therapy treatment of shoulder pain: a randomized clinical trial. *J Orthop Sports Phys Ther.* 2017;47(1):11-20. doi: 10.2519/jospt.2017.6698.
 186. Jayaseelan DJ, Moats N, Ricardo CR. Rehabilitation of proximal hamstring tendinopathy utilizing eccentric training, lumbopelvic stabilization, and trigger point dry needling: 2 case reports. *J Orthop Sports Phys Ther.* 2014;44(3):198-205. doi: 10.2519/jospt.2014.4905.
 187. Morelli KM, Brown LB, Warren GL. Effect of NSAIDs on recovery from acute skeletal muscle injury: a systematic review and meta-analysis. *Am J Sports Med.* 2018;46(1):224-233. doi: 10.1177/0363546517697957.
 188. Boudreault J, Desmeules F, Roy JS, Dionne C, Fremont P, Macdermid JC. The efficacy of oral non-steroidal anti-inflammatory drugs for rotator cuff tendinopathy: a systematic review and meta-analysis. *J Rehabil Med.* 2014;46(4):294-306. doi: 10.2340/16501977-1800.

189. Andres BM, Murrell GA. Treatment of tendinopathy: what works, what does not, and what is on the horizon. *Clin Orthop.* 2008;466(7):1539-1554. doi: 10.1007/s11999-008-0260-1.
190. Mackey AL, Mikkelsen UR, Magnusson SP, Kjaer M. Rehabilitation of muscle after injury - the role of anti-inflammatory drugs. *Scand J Med Sci Sports.* 2012;22(4):e8-14. doi: 10.1111/j.1600-0838.2012.01463.x.
191. Coombes BK, Bisset L, Vicenzino B. Efficacy and safety of corticosteroid injections and other injections for management of tendinopathy: a systematic review of randomised controlled trials. *Lancet.* 2010;376(9754):1751-1767. doi: 10.1016/S0140-6736(10)61160-9.
192. Mellor R, Bennell K, Grimaldi A, et al. Education plus exercise versus corticosteroid injection use versus a wait and see approach on global outcome and pain from gluteal tendinopathy: prospective, single blinded, randomised clinical trial. *BMJ.* 2018;361:k1662. doi: 10.1136/bmj.k1662.
193. Coombes BK, Connelly L, Bisset L, Vicenzino B. Economic evaluation favours physiotherapy but not corticosteroid injection as a first-line intervention for chronic lateral epicondylalgia: evidence from a randomised clinical trial. *Br J Sports Med.* 2016;50(22):1400-1405. doi: 10.1136/bjsports-2015-094729.
194. Zhou Y, Wang JH. PRP treatment efficacy for tendinopathy: A review of basic science studies. *Biomed Res Int.* 2016;2016:9103792. doi: 10.1155/2016/9103792.
195. Hammond JW, Hinton RY, Curl LA, Muriel JM, Lovering RM. Use of autologous platelet-rich plasma to treat muscle strain injuries. *Am J Sports Med.* 2009;37(6):1135-1142. doi: 10.1177/0363546508330974.
196. Fitzpatrick J, Bulsara M, Zheng MH. The effectiveness of platelet-rich plasma in the treatment of tendinopathy: a meta-analysis of randomized controlled clinical trials. *Am J Sports Med.* 2017;45(1):226-233. doi: 10.1177/0363546516643716.
197. Miller LE, Parrish WR, Roides B, Bhattacharyya S. Efficacy of platelet-rich plasma injections for symptomatic tendinopathy: systematic review and meta-analysis of randomised injection-controlled trials. *BMJ Open Sport Exerc Med.* 2017;3(1):e000237. doi: 10.1136/bmjsport-2017-000237.
198. Grassi A, Napoli F, Romandini I, et al. Is platelet-rich plasma (PRP) effective in the treatment of acute muscle injuries? A systematic review and meta-analysis. *Sports Med.* 2018;48(4):971-989. doi: 10.1007/s40279-018-0860-1.
199. Moraes VY, Lenza M, Tamaoki MJ, Faloppa F, Belotti JC. Platelet-rich therapies for musculoskeletal soft tissue injuries. *Cochrane Database Syst Rev.* 2013;(12):CD010071. doi:10.1002/14651858.CD010071.pub2.
200. Goswami A. Prolotherapy. *J Pain Palliat Care Pharmacother.* 2012;26(4):376-378. doi: 10.3109/15360288.2012.734900.
201. Reeves KD, Sit RW, Rabago DP. Dextrose prolotherapy: a narrative review of basic science, clinical research, and best treatment recommendations. *Phys Med Rehabil Clin N Am.* 2016;27(4):783-823. doi: 10.1016/j.pmr.2016.06.001.
202. Hauser RA, Lackner JB, Steilen-Matias D, Harris DK. A systematic review of dextrose prolotherapy for chronic musculoskeletal pain. *Clin Med Insights Arthritis Musculoskelet Disord.* 2016;9:139-159. doi: 10.4137/CMAMD.S39160.
203. Neph A, Onishi K, Wang JH. Myths and facts of in-office regenerative procedures for tendinopathy: literature review. *Am J Phys Med Rehabil.* 2018. doi: 10.1097/PHM.0000000000001097.
204. Tsai SW, Hsu YJ, Lee MC, Huang HE, Huang CC, Tung YT. Effects of dextrose prolotherapy on contusion-induced muscle injuries in mice. *Int J Med Sci.* 2018;15(11):1251-1259. doi: 10.7150/ijms.24170.
205. Wang CJ. Extracorporeal shockwave therapy in musculoskeletal disorders. *J Orthop Surg Res.* 2012;7:11-799X-7-11. doi: 10.1186/1749-799X-7-11.
206. Zissler A, Steinbacher P, Zimmermann R, et al. Extracorporeal shock wave therapy accelerates regeneration after acute skeletal muscle injury. *Am J Sports Med.* 2017;45(3):676-684. doi: 10.1177/0363546516668622.
207. van der Worp H, van den Akker-Scheek I, van Schie H, Zwerver J. ESWT for tendinopathy: technology and clinical implications. *Knee Surg Sports Traumatol, Arthrosc.* 2013;21(6):1451-1458. doi: 10.1007/s00167-012-2009-3.
208. Speed C. A systematic review of shockwave therapies in soft tissue conditions: focusing on the evidence. *Br J Sports Med.* 2014;48(21):1538-1542. doi: 10.1136/bjsports-2012-091961.
209. Schmitz C, Csaszar NB, Milz S, et al. Efficacy and safety of extracorporeal shock wave therapy for orthopedic conditions: a systematic review on studies listed in the PEDro database. *Br Med Bull.* 2015;116:115-138. doi: 10.1093/bmb/ldv047.
210. Korakakis V, Whiteley R, Tzavara A, Malliaropoulos N. The effectiveness of extracorporeal shockwave therapy in common lower limb conditions: a systematic review including quantification of patient-rated pain reduction. *Br J Sports Med.* 2018;52(6):387-407. doi: 10.1136/bjsports-2016-097347.
211. Chiavaras MM, Jacobson JA. Ultrasound-guided tendon fenestration. *Semin Musculoskelet Radiol.* 2013;17(1):85-90. doi: 10.1055/s-0033-1333942.

212. Krey D, Borchers J, McCamey K. Tendon needling for treatment of tendinopathy: a systematic review. *Phys Sportsmed*. 2015;43(1):80-86. doi: 10.1080/00913847.2015.1004296.
213. Chaudhry FA. Effectiveness of dry needling and high-volume image-guided injection in the management of chronic mid-portion Achilles tendinopathy in adult population: a literature review. *Eur J Orthop Surg Traumatol*. 2017;27(4):441-448. doi: 10.1007/s00590-017-1957-1.
214. Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports*. 2008;18(1):40-48. doi: 10.1111/j.1600-0838.2006.00634.x
215. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med*. 2006;34(8):1297-1306. doi: 10.1177/0363546505286022.
216. McHugh MP, Cosgrave CH. To stretch or not to stretch: the role of stretching in injury prevention and performance. *Scand J Med Sci Sports*. 2010;20(2):169-181. doi: 10.1111/j.1600-0838.2009.01058.x.
217. Goode AP, Reiman MP, Harris L, et al. Eccentric training for prevention of hamstring injuries may depend on intervention compliance: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49(6):349-356. doi: 10.1136/bjsports-2014-093466.
218. Maravelias C, Dona A, Stefanidou M, Spiliopoulou C. Adverse effects of anabolic steroids in athletes. A constant threat. *Toxicol Lett*. 2005;158(3):167-175. doi: 10.1016/j.toxlet.2005.06.005.
219. Urban RJ. Growth hormone and testosterone: anabolic effects on muscle. *Horm Res Paediatr*. 2011;76 Suppl 1:81-83. doi: 10.1159/000329184.
220. Phillips SM. Protein requirements and supplementation in strength sports. *Nutrition*. 2004;20(7-8):689-695. doi: 10.1016/j.nut.2004.04.009.
221. Kreider RB. Dietary supplements and the promotion of muscle growth with resistance exercise. *Sports Med*. 1999;27(2):97-110. doi: 10.2165/00007256-199927020-00003
222. Ciocca M. Medication and supplement use by athletes. *Clin Sports Med*. 2005;24(3):719-38, x-xi. doi: OI: 10.1016/j.csm.2005.03.005.
223. Lanher C, Pereira B, Naughton G, Trousselard M, Lesage FX, Dutheil F. Creatine supplementation and upper limb strength performance: a systematic review and meta-analysis. *Sports Med*. 2017;47(1):163-173. doi: 10.1007/s40279-016-0571-4.
224. Lanher C, Pereira B, Naughton G, Trousselard M, Lesage FX, Dutheil F. Creatine supplementation and lower limb strength performance: a systematic review and meta-analyses. *Sports Med*. 2015;45(9):1285-1294. doi: 10.1007/s40279-015-0337-4.
225. Chilibeck PD, Kaviani M, Candow DG, Zello GA. Effect of creatine supplementation during resistance training on lean tissue mass and muscular strength in older adults: a meta-analysis. *Open Access J Sports Med*. 2017;8:213-226. doi: 10.2147/OAJSM.S123529.
226. Bouchard R, Weber AR, Geiger JD. Informed decision-making on sympathomimetic use in sport and health. *Clin J Sport Med*. 2002;12(4):209-224.
227. Hsu CJ, Meierbachtol A, George SZ, Chmielewski TL. Fear of reinjury in athletes. *Sports Health*. 2017;9(2):162-167. doi: 10.1177/1941738116666813.

NOTES

NOTES

Tissue Tolerances of the Muscle-Tendon Unit**REVIEW QUESTIONS**

For each of the following questions, pick the most appropriate option. Correct answers, including rationale, are provided to enhance understanding.

1. A number of factors other than the muscle-tendon unit itself play a significant role in the capability of an individual to perform various movements. In a patient who recently sustained a grade II supraspinatus injury 4 days prior, which of the following would be most associated with a positive long-term outcome?
 - a. diabetes type II.
 - b. hypercholesterolemia.
 - c. the patient being 22 years old.
 - d. reduced willingness to move.

2. After a rotator cuff repair, the patient was placed in a brace and was expected to use it for the first 2 weeks. Based on biomechanical considerations, which position of bracing would be most advantageous for the rotator cuff MTU in the early phase of healing?
 - a. full shoulder external rotation (to tolerance).
 - b. full shoulder internal rotation (to tolerance).
 - c. slight shoulder abduction, neutral rotation.
 - d. slight shoulder adduction, neutral rotation.

3. A patient is 3 months postoperative from a rotator cuff repair. He has functional range of motion, but continues to have pain in his shoulder. He believes if his pain were to decrease, he would be completely satisfied with his current level of function and status. Which mode of exercise would likely be most effective in managing this patient's pain at this time?
 - a. concentric exercise.
 - b. eccentric exercise.
 - c. heavy slow resistance exercise.
 - d. isometric exercise.

4. A 52-year-old female presents with complaints of chronic elbow pain, which has not gotten better despite numerous episodes of treatment with physical therapists, massage therapists, chiropractors, sports medicine doctors, and acupuncture. The ongoing pain has become frustrating, and she is seeking any option that could reduce her pain. She expresses interest in getting a cortisone injection, which she

was told could help, and is interested in your thoughts. According to the evidence, you explain that:

- a. short- and long-term outcomes associated with injection are poor.
- b. short-term outcomes are poor but long-term outcomes are good.
- c. short-term outcomes are good but long-term outcomes are poor.
- d. short- and long-term outcomes associated with injection are good.

5. Achilles tendon pathology is frequently described from a histopathological perspective. Which pathological diagnosis most accurately describes '*Collagen disorientation, fiber separation with increase in mucoid ground substance, increased presence of cells and vascular spaces with or without neovascularization and focal areas of necrosis and calcification?*'?
 - a. tendinitis.
 - b. tendinosis.
 - c. paratenonitis.
 - d. synovitis.

6. A recreational runner presents to your clinic with primary complaints of posterior thigh pain for the past day, after starting a new speed workout. He stopped after the pain started, but was able to jog home. He has some pain with resistive testing of the hamstrings, tenderness at the ischial tuberosity and a positive straight leg raise at 71° with radiating pain into the knee. What would be your primary intervention at the first visit?
 - a. deep transverse friction mobilization of the conjoint hamstring tendon.
 - b. modified planks to tolerance to maintain lumbopelvic stability.
 - c. neurodynamic sliders of the sciatic nerve at 45° hip flexion.
 - d. submaximal isometric heel digs in slight knee flexion.

7. Muscle and tendon healing capacity differs greatly, and relies on countless variables. Of the following scenarios, assuming good medical status outside of the explicitly noted factors, which patient would likely have the best opportunity to heal?
 - a. a 25-year-old male with a grade III rotator cuff tear who has been noncompliant with his postoperative rehabilitation.
 - b. a 45-year-old female with a grade II Achilles tendon tear who has been compliant with her postoperative rehabilitation.
 - c. a 65-year-old male with a grade IV rotator cuff tear who has been noncompliant with his postoperative rehabilitation.
 - d. a 75-year-old female with a grade III Achilles tendon tear who has been compliant with her postoperative rehabilitation.

- a. a 16-year-old male with diabetes mellitus type I.
 - b. a 32-year-old male taking Avelox.
 - c. a 40-year-old obese male.
 - d. a 42-year-old male smoker.
8. Physical therapists have training in musculoskeletal radiology, which assists them in the decision-making process when considering appropriate services for a patient. Which of the following statements most accurately describes the role of musculoskeletal imaging in muscle-tendon unit pathology?
- a. diagnostic imaging modalities may assist in the staging of tendinopathic changes, when coupled with clinical examination, to determine appropriate interventions.
 - b. owing to the high frequency of detecting pathology in the asymptomatic population, advanced imaging studies are irrelevant in the management of muscle-tendon unit dysfunction.
 - c. there is a strong positive correlation between tendon structure and symptom report, suggesting that individuals with tendinopathy should obtain diagnostic ultrasound.
 - d. the primary benefit of imaging is to assist in surgical intervention planning or when performing tendon nee-
dling or fenestration.
9. Tendinous tissue should have strength to allow transference of force from muscle to bone, as well as pliability to adapt to different joint positions. These multiple functions can be performed due in part to its structural composition. The extracellular matrix makes up about 80% of a tendon. Which of the following makes up the greatest proportional component of the extracellular matrix?
- a. collagen.
 - b. elastin.
 - c. proteoglycans.
 - d. water.
10. The force production of muscle is dependent on a variety of factors. Which of the following statements is accurate?
- a. an immobilized muscle will be considerably weaker than one not immobilized.
 - b. greater forces can be generated by more rapid voluntary contractions.
 - c. the smaller the cross-sectional area, the greater the force that can be developed.
 - d. the stretch-shortening cycle is associated with electrical silence on EMG.

ANSWERS

1. c

Rationale: Co-morbidities (DM type II, hypercholesterolemia) have been shown to delay the healing process and clinically weaken tendon tissue. In the case of rotator cuff injuries, DM specifically is associated with stiffer shoulders and worse prognoses. A fear of movement may be expected given the relative recent post-op status; however, fear and perseverance of disability is associated with worse outcomes and increased likelihood of nervous system sensitization. The patient's age would be the best prognostic factor of the options provided. With aging comes a reduction in MTU capacity; however, the physiological decline is more pronounced after the age of 60. A 22-year-old would be expected to recover well, assuming no co-morbidities.

2. c

Rationale: When considering the length-tension relationship, the MTU works best actively from a mid-range position. Immobilization in a shortened position has been associated with worse outcomes in the long term, and immobilization in a lengthened position would likely create too much tensile force on the healing tissues. While specific positioning may play a role, shoulder adduction could be associated with increased compressive or tensile load on the cuff insertion.

3. d

Rationale: Any exercise could be beneficial in reducing pain to some extent, but isometric exercise would be the most appropriate in this case. Concentric exercise is functional, yet its immediate pain reducing effects are not substantial. Eccentric exercise has demonstrated significant assistance in reducing pain and improving function for patients with tendinopathy, but typically it does not provide immediate pain-reducing effects, but helps after at least 4-week duration programs. Heavy slow resistance is effective in reducing pain and improving patient satisfaction in the short and long-term, but efficacy in the shoulder has not been demonstrated to date. Isometric exercise has good evidence to support its use in reducing pain in the short term in the upper and lower extremity, as well as for the chronic pain population.

4. c

Rationale: Numerous randomized trials and systematic reviews have reported that CSI may have a pain-reducing effect in the immediate and short term; however, at longer term follow-up, there is a wash out effect, and in some cases, outcomes are worse than doing nothing. Corticosteroid injections may have deleterious effects on tendon tissue and structure, so despite their short-term pain relief for MTU pathology, they should be used sparingly.

5. b

Rationale: Various classification systems exist, but this is taken from Bonar's modification of Clancy's classification of tendinopathy. While additional imaging studies are not requisite to make a clinical diagnosis of Achilles tendinopathy, it is useful to understand what is occurring at a histopathological level within the tendon to intervene appropriately.

6. d

Rationale: The patient presents with what appears to be a lower grade hamstring injury. In some cases, given the proximity of the hamstring origin and sciatic nerve at the sciatic notch, neural irritation is not uncommon with MTU injury. Neural intervention would not be a priority at this time, since it is likely a secondary problem. Deep friction mobilization would likely exacerbate the condition, given the acuity. The purpose of DFM is to stimulate an inflammatory response; however, if the injury was yesterday, the patient is still in the acute/inflammatory phase. Modified planks could be helpful to maintain lumbopelvic control and stability, but do not address the primary injury. The purpose in phase I of muscle injury rehabilitation is to protect the injury site, decrease pain, and prevent atrophy. To do these things, submaximal isometrics in a slacked position would be the most appropriate option.

7. b

Rationale: Diabetes, obesity, and a smoking history all will blunt a tissue repair to some extent, likely resulting in a prolonged healing process compared to individuals without these conditions. Avelox is an antibiotic, prescribed in response to a skin, respiratory, or sexually-transmitted disease. Fluoroquinolones have been associated with medication-induced tendinopathies, but have not necessarily been associated with dampening of a tissue repair process.

8. a

Rationale: The usefulness of imaging in evaluating and treating MTU pathology is somewhat unclear. Imaging can assist in diagnosing and staging a condition (eg, location of an Achilles muscle injury and extent of injury) but is also quite helpful in ruling out other competing diagnoses. Although a proportion of asymptomatic individuals demonstrate abnormal imaging studies, and tendon structure is not necessarily linked to symptoms, imaging still may play a role. For example, for a patient in the degenerative tendinopathy stage, US findings may confirm a clinical diagnosis that requires progressive load management. While it should be used sparingly, imaging, when coupled with patient report and physical examination, may have a confirmatory role in appropriateness for treatment.

9. d

Rationale: The ECM is 55-70% water. The remaining percentage of the ECM is primarily solids: mostly collagen, but also proteoglycans, elastin, and other proteins.

10. a

Rationale: Immobilization has deleterious effects on muscle tissue, reducing the mass and force production within only days for healthy subjects, and even less for individuals with injury or pathology. The other options are incorrect. Greater force can be generated with slower (or more controlled) contractions, the greater the CSA the greater force generation capacity, and while the SSC takes advantage of energy storage and tissue elasticity, muscle activity still occurs and will be captured on EMG monitoring.