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COMMENTARY

Biotensegrity Is Needed in Athletic Training Professional Education

David Tomchuk, DAT, ATC, LAT, CSCS*; Barton E. Anderson, DHSc, ATC†
*Department of Kinesiology, Nutrition and Recreation, Southeast Missouri State University, Cape Girardeau †Department of Interdisciplinary Health Sciences, Arizona School of Health Sciences, A.T. Still University, Mesa

Context: *Tensegrity* is a structural-organization model initially described in the architecture and design fields. By applying tensegrity design principles to biological structures, scientists have developed *biotensegrity* to explain a complex systems-on-systems structural-organization philosophy for integrated human movements.

Objective: To provide a brief historical overview of tensegrity and biotensegrity principles, including recommendations and benefits for integrating these structural models into athletic training education.

Background: Tensegrity and biotensegrity structures require constant interaction between continuous tension and discontinuous compression elements that connect through focal adhesion points. During the 1970s and 1980s, scientists applied tensegrity concepts to biological organisms to create an integrated model of human structure and interaction. Since then, biotensegrity has grown as an accepted biological structural model capable of explaining complex and integrated human movements.

Synthesis: By teaching tensegrity and biotensegrity principles, athletic training educators can provide athletic training students with a basic and consistent human body structural model. With this knowledge, students can better comprehend the integrated kinetic chain, including current and future prevention, examination, and rehabilitation paradigms.

Results: Although absent from the Practice Analysis, seventh edition, and the 2020 Commission on Accreditation of Athletic Training Education curricular content standards, tensegrity and biotensegrity relate to many injury prevention, examination, treatment, and rehabilitation concepts regularly taught in professional athletic training programs.

Recommendation(s): Athletic training educators should consider ways to incorporate biotensegrity models into professional athletic training programs to improve critical thinking and whole-person health care principles of athletic training students.

Conclusion(s): Integrating tensegrity and biotensegrity principles into professional athletic training programs provides a structural hierarchy of human body organization that athletic training students can apply to a multitude of current and future methodical approaches.

Key Words: Biology, structure, force, curriculum, instruction

Dr Tomchuk is currently an Assistant Professor in the Department of Kinesiology, Nutrition, and Recreation at Southeast Missouri State University. Please address correspondence to David Tomchuk, DAT, ATC, LAT, CSCS, Department of Kinesiology, Nutrition and Recreation, Southeast Missouri State University, One University Plaza, MS 7650, Cape Girardeau, MO 63701. dtomchuk@semo.edu.

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Biotensegrity Is Needed in Athletic Training Professional Education

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KEY POINTS

- Based on tensegrity design principles, biotensegrity is a structural and functional model that helps explain human anatomy and function.
- Biotensegrity structures include components of continuous tension and discontinuous compression that distribute stress from internal and external forces throughout the entire structure.
- The human body is a biotensegrity structure in which bones represent the compression units and soft connective tissues (fascia, tendons, cartilage, muscles, ligaments) are the tension units.
- Biotensegrity principles can be used to enhance the teaching of examination and rehabilitation approaches, especially for insidious onset conditions such as patellofemoral syndrome and low back pain, by expanding the student's understanding of regional interdependence and whole-body functioning.
- To enhance the understanding of prevention, examination, treatment, and rehabilitation paradigms, athletic training students should be exposed to biotensegrity principles during their professional education.

INTRODUCTION

To facilitate patient-centered care during the 21st century, health professions, including athletic training and physical therapy, have shifted from the biomedical model, which focuses on examining and treating isolated musculoskeletal structures, to the biopsychosocial model and incorporation of disablement model frameworks focusing on whole-person health care.[1–3] Approaches to injury examination and diagnosis have transitioned from a singular focus on pain-generating tissues at the site of injury to an appreciation of the underlying pathomechanics and abnormalities that may occur distal or proximal to the reported injury site. This concept of "regional interdependence" has been embraced for the diagnosis and treatment of insidious onset conditions, such as patellofemoral syndrome, nonspecific chronic low back pain, and others.[1,4,5] For example, hip-muscle weakness has been identified as a causative factor for patellofemoral pain[6–8] and chronic ankle instability,[9,10] whereas reduced hip mobility has been shown to contribute to low back pain[11,12] and postural adaptations contribute to subacromial impingement.[13,14] Understanding concepts of whole-body biomechanics and movement dysfunction aids the diagnostic process for insidious onset musculoskeletal conditions, enhances rehabilitation outcomes by targeting specific underlying causes of pain and dysfunction, and improves understanding of human performance and potential injury risk factors.[5]

Injury prevention, examination, and rehabilitation techniques have also evolved over the last 2 decades, connecting the site of pain to dysfunctional proximal and distal structures that contribute to adverse tissue stress.[15–17] Athletic training students are commonly introduced to examination techniques for posture assessment,[18] movement analysis,[19,20] and regional interdependence,[1,4] along with intervention strategies such as corrective exercises to address sensorimotor system deficits,[21–23] and kinesiology taping,[24] instrument-assisted soft tissue mobilization,[25] foam rolling,[26] and myofascial release[27] to address the underlying causes of tissue dysfunction and pain. Despite these shifts toward a holistic approach to examination, diagnosis, and treatment, in athletic training education the theoretical models used to teach these concepts remain focused on individual structures and traditional biomechanical principles, firmly rooted in the biomedical model. Therefore, the purpose of this commentary is to introduce athletic training educators to the principles of biotensegrity and to provide recommendations and examples to support the integration of the biotensegrity model into professional athletic training programs.

Brief History of Tensegrity and Biotensegrity

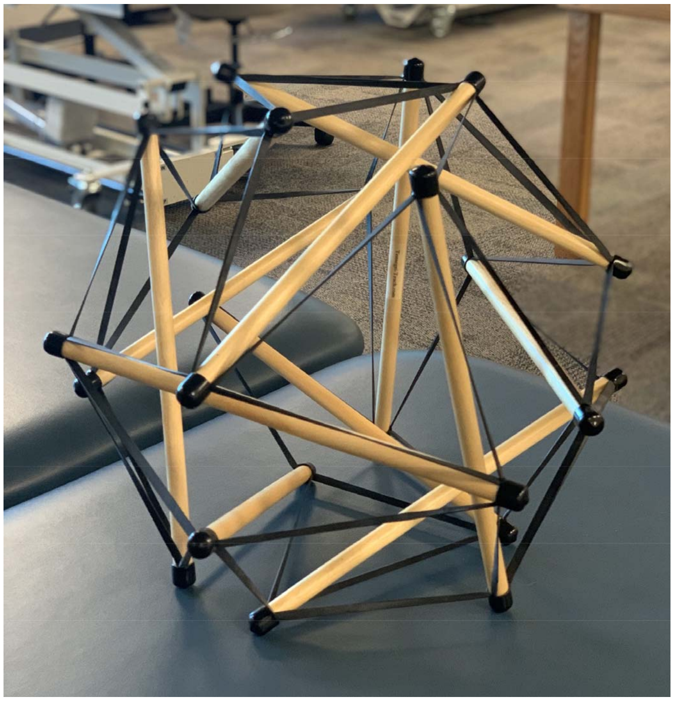
Tensegrity is a structural organization concept first described by architects, designers, and artists.[28] The word *tensegrity* is a portmanteau derived from a combination of tension and integrity (*tens*ion + int*egrity* = *tensegrity*) and refers to structures comprising continuous tension units surrounding discontinuous compression units. The sculptors Karlis Johansons and Kenneth Snelson independently developed and displayed self-tensioned structures before the American architect Buckminster Fuller popularized geodesic domes (strong, stable structures built out of patterns of repeating triangles[29]) as tensegrity structures in the architecture profession.[28,30–32]

During the late 1970s and early 1980s, Donald Ingber applied tensegrity theory to explain cellular biology findings in which single cells became rounded and raised without external connections.[28,33] The orthopedic surgeon Stephen Levin applied tensegrity principles to whole biological organisms in the early 1980s to postulate about external force transmission, movement, biological organization, and musculoskeletal injuries.[28,34] These initial scientific pioneers applied the concepts of tensegrity to explain biological microstructural and macrostructural orientation, force generation and transmission, and integrated human movement, culminating in the coining of the term *biotensegrity* (*bio*logical + *tens*ional + int*egrity* = *biotensegrity*) to explain the unique principles of tensegrity architecture applied to biological systems.[28] *Biotensegrity* represents the overarching structural model that explains human movement and function.[17]

Tensegrity Structure Characteristics

A tensegrity structure exists in a prestressed state in which a series of discontinuous compression components regularly interact within a web of continuous tension components (Figure 1).[28,35,36] Through this constant interaction, the prestressed tensegrity structure rearranges its internal orientation on the basis of applied internal and external forces, creating an extremely stable configuration.[28,35]

Figure 1. Tensegrity icosahedron showing discontinuous compression-resistant components (dowels), continuous tension components (black elastic bands), and focal adhesion points (rubber caps).



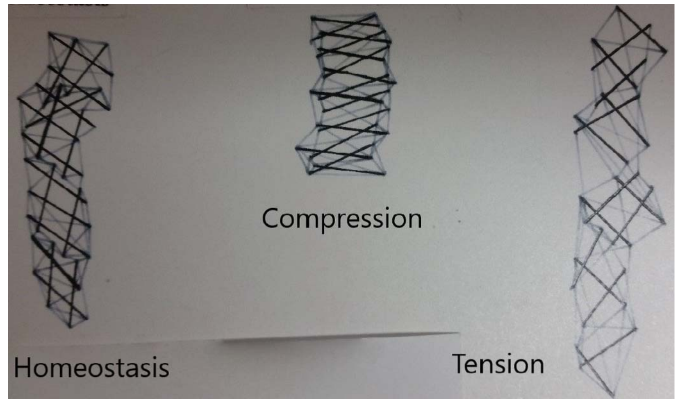
Because all of the tension components in the structure are stressed continuously, tensegrity structures intrinsically self-stabilize.[28,35] This self-stabilizing capacity comes from the ability to immediately transmit forces multidirectionally throughout the structure without physical, electronic, or neurological inputs.[28,35,37] This interconnectedness also creates the capacity to dissipate and transmit forces throughout the entire structure, preventing excessive localized damage. Finally, the nature of prestressed tension components enables tensegrity structures to regain their original form immediately after removal of an internal or external force, which ensures the ability to recover following load generation or application (Figure 2).[28]

Biotensegrity in the Human Body

Each biological tissue layer, from individual cells (micro) to the entire human body (macro), has unique biotensegrity components. At the cellular level, discontinuous compression components are represented by the microtubules and cytoskeleton, and continuous tension components are represented by microfilaments within the cell.[35] At the macro level, bones represent the discontinuous compression-resistant components, whereas soft tissues including fascia, tendons, cartilage, muscles, and ligaments represent tension components.[28,35,38]

By the early 1980s, Robbie[39] and Levin[34] were questioning the established view that the spinal column functions as a "stack of blocks" that transmits compressive loads. However, the vertebrae are not stacked in direct vertical alignment, but rather each vertebra is suspended inside a continuous tension network of muscles, ligaments, discs, and fascia that maintains organization of the spine regardless of position and without structural failure.[34] The bones of the human skeleton are separated by articular cartilage, allowing them to act as the discontinuous compression components of the body.[34] Large-scale evidence for this becomes apparent when examining fascia, ligaments, and muscles. These tissues rarely relax completely and are subject to increases and decreases in tension through mechanical and neurological inputs, thus making them the ideal continuous tension components.[34] These tension structures surround the bones and provide a means to promote stability of the body regardless of position or task and a mechanism to return to their original shape after removing an internal or external force.

Figure 2. Cellular biotensegrity under different conditions: homeostasis (left), compression (center), and tension (right).

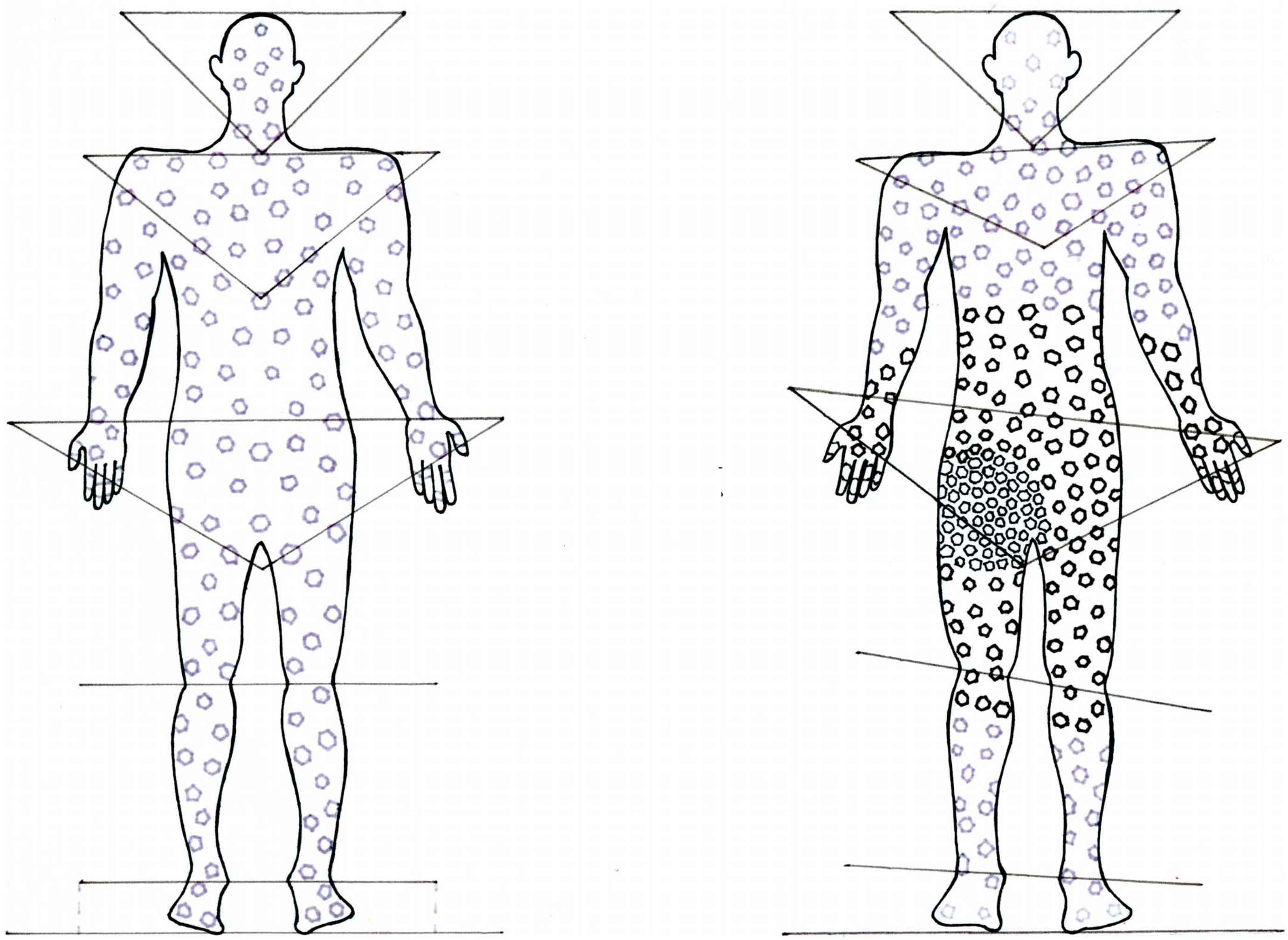


Biotensegrity Applied to Injury Models and Examination

Biotensegrity provides a structural model of the human body that helps us better understand human movement, kinetic chain interactions, and contemporary injury theories. To begin, biotensegrity explains how mechanical tissue restrictions can limit normal physiological motion and cellular function both locally and remotely.[28] For example, when there is an increase in local tension within a tissue, perhaps from repetitive sports or physical activities, that increased tension is distributed throughout surrounding structures, causing an alteration in the tissue's shape.[28] This alteration can propagate from a local increase in tissue tension to the entire musculoskeletal structural unit owing to the continuous, connected nature of the soft tissues within the biotensegrity model. Over time, the temporarily altered tissue state can become a prolonged postural or pathological adaptation, resulting in dysfunction and discomfort (Figure 3).

A classic example of this phenomenon is the common postural adaptation of an anteriorly tilted pelvis and increased lordotic curve seen in many athletes and patients complaining of low back pain.[40] Repetitive sports or physical activities cause an increase in the tension of the hip flexors and back extensors. These areas of increased tension are coupled with areas of decreased tension in the lower abdominals and hip extensors, resulting in an anterior pelvic tilt, increased lordosis, and increased kyphosis (Figure 4).[40] These local areas of altered soft tissue tension, when viewed as part of the continuous tension components within the biotensegrity model, result in adaptations of the spinal curves and a change in the shape of the entire structure.[40] Application of the biotensegrity model to these common postural adaptations shifts the focus from

Figure 3. Organism-level effects of biotensegrity alterations. Nonpathological biotensegrity (left) and pathological biotensegrity adaptations after a prolonged injury to the patient's right hip flexor (right).

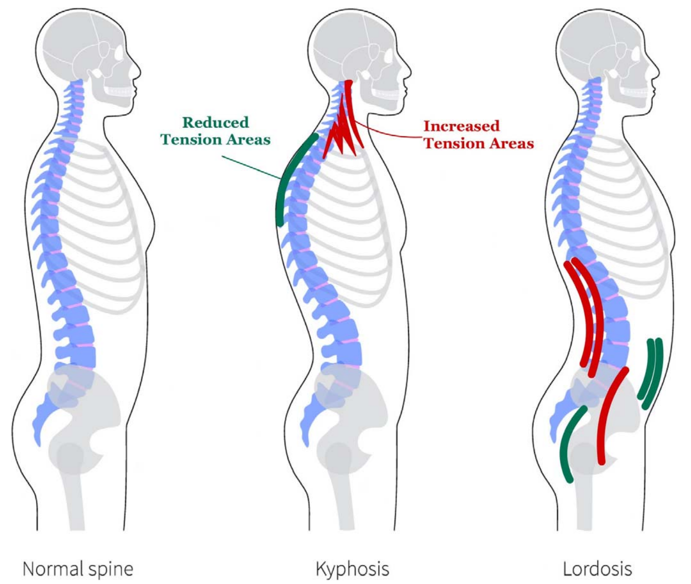


the isolated local structures (pelvic position and muscular strength) to the connected relationships of the entire body.

Patellofemoral syndrome (PFS) is another example of how biotensegrity can aid in our understanding of the condition, and specifically how our understanding has evolved. Originally identified as a patellofemoral-joint–tracking dysfunction caused by poor quadriceps and vastus medialis oblique strength, the theoretical understanding of PFS has evolved to include underlying causes of dysfunction originating proximally from the trunk, core, and hip, as well as distally from the feet.[41] Weakness and dysfunction in the core musculature, hip abductors, and external rotators are now considered primary factors in adverse patellofemoral joint stress due to a dynamic valgus collapse.[8] Application of the biotensegrity model allows visualization of these muscles and their associated fascial and soft tissue networks as units of continuous tension, which, when functioning normally, maintain patellofemoral joint alignment by preventing excessive adduction and internal rotation of the femur and excessive compressive forces at the patellofemoral joint. Altered levels of tension in these structures, usually due to reduced muscle activation, result in increased femoral adduction and femoral internal rotation, as well as transmission of forces throughout the lower extremity.[8] This manifests as pain at the patellofemoral joint due to excessive articular surface compression.[7] As our understanding of biotensegrity principles increases, so does our understanding of connections across different body tissues and regions.

Biotensegrity aids our understanding of chronic conditions caused by regional structures—conditions such as PFS, chronic low back pain, tendinopathies, and other insidious onset conditions. It is also useful in understanding possible injury risk factors associated with movement dysfunctions, mobility limitations, and stability deficits, such as how internal rotation deficits affect the throwing shoulder[42] or how dorsiflexion limitations can result in the development of patellar tendinopathy.[43] Incorporation of the biotensegrity model shifts the clinician's focus from isolated anatomical structures at the site of pain to a more global view of the body as a series of interconnected tensional structures (fascia, tendons, cartilage, muscle, ligaments) surrounding local compression units (bones). This shift lends itself to the examination process and identification of causal factors for injuries, and the selection and implementation of rehabilitation and treatment approaches. Integration of biotensegrity concepts and principles into athletic training education would instill this expanded view of the body and underlying causes for injury in athletic training students at the beginning of their career, reinforcing the biopsychosocial model of patient care.

Figure 4. Biotensegrity in the manifestation of low back pain. Normal distribution of tension allows for normal spinal curves (left). Increased tension in the scalenes and sternocleidomastoid creates an anterior pull on the cervical spine, resulting in increased kyphosis (center). Increased tension in the iliopsoas and erector spinae muscle group coupled with reduced tension in the transverse abdominis and gluteals results in anterior pelvic tilt and increased lordosis (right).



Biotensegrity Applied to Patient Symptoms and Therapeutic Interventions

Biotensegrity also helps explain why a patient's primary complaint may not accurately reflect the location of tissue damage or underlying biomechanical causes of dysfunction.[1,4,17] If we accept that within the biotensegrity model the musculoskeletal tissues are continuously connected and under tension, it becomes easier to visualize how stress from one region of the body can be transmitted to distant structures above or below the site of dysfunction. These connections improve our understanding of a variety of chronic conditions and their possible causes, including the previous examples of PFS and low back pain. Considering the human body as a biotensegrity structure can also improve student and clinician understanding of a multitude of conventional and contemporary therapeutic interventions, including manual therapies (eg, massage, mechanical traction, joint mobilizations, positional release), soft tissue techniques (eg, instrument-assisted soft tissue mobilization, kinesiology taping, myofascial release) and targeted corrective exercises.

Most manual therapies and soft tissue techniques focus on restoring tissue to its normal physiological length and resting tone.[27,44] These treatments result in reduced tension throughout the entire tension network, returning the body to its homeostatic shape and tension. After successful treatment, the muscle and fascia begin operating normally, without producing long-term mechanical dysfunction.[28] Both manual therapies and soft tissue techniques rely on mechanotransduction for their success.

Mechanotransduction is the conversion of mechanical signals into electrochemical activity within the body, and it is considered a major form of cellular communication.[28] When the body undergoes a mechanical load, whether from movement of tissues during daily activities, application of manual therapy techniques, or soft tissue treatments, the mechanical stimulus deforms the target tissues; this mechanical signal is transmitted through the extracellular matrix to the cells, which then integrate these signals with other biochemical messages to produce their cellular response.[31] Mechanotransduction is only possible because of the continuous tension network within the body and the connection of the cells to the extracellular matrix, as demonstrated within the biotensegrity model.[1,30,31,45] Mechanotransduction explains how fibroblasts lay down new collagen fibers along the lines of tissue stress during the healing process;[46] how myofascial release works to improve the functioning of the extracellular matrix and fiber gliding within tissues;[27] and how positional release therapy (strain-counterstrain) can reduce soft tissue tension by placing a body part in a position of comfort.[47] These are just a few examples of common therapeutic interventions that athletic training students learn as part of their didactic and clinical education; incorporation of biotensegrity principles can only aid in their understanding of the physiologic and biomechanical effects of these interventions.

Integration of Biotensegrity Into Athletic Training Education

Other health care professions have recently advocated for the use of biotensegrity as the structural model for human movement and function.[4,28,48] Biotensegrity has been identified as the mechanism by which osteopathic manipulation restores physiologic motion.[28] The physical therapy profession has described the inclusion of a movement system in entry-level training, research, and professional practice and detailed the emphasis on regional interdependence and biotensegrity concepts.[1,49–51] Manual therapists have explicitly identified biotensegrity as the primary scientific theory that informs their clinical decision-making process, through validation of a more inclusive movement-driven treatment approach, compared with the standard biomechanical approach.[48]

We believe that athletic training would also benefit from the incorporation of biotensegrity concepts into professional and postprofessional education. This educational approach would be in stark contrast to the traditional reductionist philosophy, whereby distinct and isolated muscle groups, tissues, and joints are evaluated and treated independently without fully appreciating the influences of the surrounding structures.[17,52,53] Athletic training educators and preceptors routinely discuss the importance of identifying the causative factor of an injury, which may not be the primary complaint. Biotensegrity does not prescribe a specific exercise protocol or promote a particular evaluation technique; it instead provides a functional and structural understanding of the human body that describes a relationship between the entire organism and a multitude of subsystems, leading to a greater holistic and biopsychosocial understanding of health comorbidities.[53,54]

By including biotensegrity in the professional curriculum, the athletic training profession can educate future professionals about this modern movement and force-transmission paradigm, which is especially important because biotensegrity

Table 1. Example Plan for Integrating Biotensegrity Into Athletic Training Courses and Curricula

Athletic Training Course Content	Foundational Concepts Supported by Biotensegrity
Anatomy, physiology, and kinesiology	Human structure and function
	Body tissue relationships
	Biomechanics and movement
Physical examination and diagnosis	Whole-person, patient-centered care
	Regional interdependence
	Identification of underlying causes of mechanical stress and chronic conditions
	Causes for common postural adaptations
	Causes for common mechanisms of injury
	Cause for movement dysfunctions
Therapeutic interventions	Mechanotransduction
	Physiologic effects of manual therapy techniques
	Physiologic effects of soft tissue mobilization techniques
	Physiologic effects of corrective exercise techniques
Strength and conditioning	Relationships between muscle strength, flexibility, neuromuscular control, and physical performances
	Causes for common performance deficits
Athletic training clinical experiences	Whole-person, patient-centered care
	Development and implementation of a comprehensive patient care plan

describes the underlying basic science of the techniques clinicians regularly perform.[54] Teaching biotensegrity to athletic training students would promote and enhance critical thinking and diagnostic examination skills that can progressively develop during their athletic training careers. Furthermore, educators can demonstrate tissue interconnectedness and apply biotensegrity to contemporary prevention, examination, treatment, and rehabilitation theories. Athletic trainers with an understanding of biotensegrity would become increasingly adept at the examination and rehabilitation process for insidious onset, chronic, and movement-based injuries. By incorporating biotensegrity into the existing examination and treatment models, athletic training students can deepen their understanding of human body structure and function to develop problem-solving and critical thinking abilities that reinforce kinetic-chain principles.

Biotensegrity is best approached as a theoretical model that explains the structural organization of the body and the contributions of this organization to normal human movement and function. Similar to overarching concepts such as evidence-based practice, patient-centered care, and the biopsychosocial model, biotensegrity should be incorporated into multiple courses throughout the athletic training program curriculum.

An ideal place to introduce these concepts is in a gross or functional anatomy course, where students can begin to learn about structure, function, and the connected nature of the human body. Once students are exposed to the concepts of biotensegrity and become familiar with the constructs of continuous tension around localized compression, they can begin to apply this framework to the examination process, further expanding their ability to visualize the body as an interconnected structure. The physical examination, when conducted through the biotensegrity lens, naturally expands from the initial site of pain to surrounding structures and tissues due to the connected nature of the body. Courses teaching treatment and rehabilitation techniques can benefit from the inclusion of biotensegrity because it provides a clear understanding of the physiologic effects of many therapeutic interventions. Regular exposure to biotensegrity concepts throughout the curriculum helps to reinforce the idea that the human body is made up of many interconnected systems that all function together. Table 1 presents examples for integrating biotensegrity principles into athletic training programs to support specific courses and curricular content. Table 2 provides resources for educators wishing to learn more about biotensegrity. The Appendix provides an example for integrating biotensegrity into a hands-on lab for a posture assessment.

CONCLUSIONS

With the increased emphasis on whole-person health care, incorporating biotensegrity into the curriculum of professional athletic training programs would facilitate a deeper understanding of human movement and health. Given the ongoing reconceptualization of the human body's structure and function, future clinicians must relate these changing concepts to clinical practice. Teaching biotensegrity as a methodological approach in injury prevention, examination, treatment, and rehabilitation courses for professional athletic training students will promote a comprehensive understanding of the integrated human organism. As a result, athletic training students will better comprehend and appreciate the interconnectedness of their patients' tissues and improve the likelihood of implementing whole-person, holistic health care protocols. By explicitly exposing athletic training students to biotensegrity principles throughout a professional program, educators will provide athletic training students with a cohesive, science-based explanation of how the human body is interconnected and why a multitude of prevention, examination, treatment, and rehabilitation strategies can be successful.

Acknowledgments

Figures 2 and 3 are artwork created by Jami Miller, ATC, LAT.

Table 2. Biotensegrity Resources for Athletic Training Educators

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Appendix. Application of Biotensegrity During Hands-On Posture Assessment

Context. *Biotensegrity* is a structural model that describes how the human body is interconnected through continuous tension structures (fascia, muscles, tendons) surrounding localized compression units (bones). This model can be used during the traditional posture assessment to identify areas of increased tension (tight muscles or fascia) and areas of decreased tension (lengthened muscles or fascia) that result in postural changes. Understanding the connected nature of the body's soft tissues aids in understanding how postural adaptations occur over time and due to repetitive stresses.

Objectives. Upon completion of this lab, students will be able to:

- Identify normal and abnormal postural alignment of the head, shoulders, spine, pelvis, knees, and feet
- Apply biotensegrity concepts of continuous tension surrounding localized compression to explain the manifestation of postural changes
- Discuss possible interventions for identified postural abnormalities

Preparatory Materials. Students should be provided with basic readings that introduce the concepts of biotensegrity, muscle hypertonicity and hypotonicity, and the postural screening process. We recommend the following:

- A physical examination textbook that includes posture assessment
- Scarr G. Biotensegrity: what is the big deal? *J Bodyw Mov Ther*. 2020;24(1):134–137.
- Observation and posture analysis—Physiotutors https://www.youtube.com/watch?v=Zp5iC3Ioq7U

Description. Have students divide into pairs or groups of 3, with 1 student's posture being assessed by the partner(s).

Instruct students to evaluate postural alignment in the anterior, lateral, and posterior views. Students should describe their subject's posture in relation to normal alignment, making notes for each of the following:

Anterior and Posterior
- Head position in relation to midline
- Shoulder height and level
- Hand position and level
- Iliac crests, ASIS, umbilicus, PSIS
- Knee position and orientation
- Foot position

Lateral
- Head position in relation to lateral line
- Shoulder position
- Thoracic curve
- Lordotic curve
- Pelvic position
- Knee position (presence of recurvatum)
- Lateral malleolus position

Abbreviations: ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.

Once students have assessed their partner's posture in the anterior, posterior, and lateral positions and made notations for any postural adaptations, instruct the students to think about the muscles and soft tissues that would be responsible for postural changes if the tissues were subjected to increased tension (hypertonicity) or reduced tension (hypotonicity).

For each postural adaptation noted, students should identify muscle groups that contribute to it through both increased tension and reduced tension.

For example,

- Forward head—increased tension (hypertonicity) of the sternocleidomastoid, scalenes, and upper trapezius; decreased tension (hypotonicity) of the deep cervical flexors
- Rounded shoulders—increased tension (hypertonicity) of the pectoralis major and minor; decreased tension (hypertonicity) of the rhomboids, middle and lower trapezius

Once the students have completed the postural screening and identified hypertonic and hypotonic muscles that contribute to postural adaptations, they can perform palpation of these specific muscle groups to gain a better understanding of how hypertonic and hypotonic tissues feel.

Discussion Questions. Depending on the level of student knowledge, ask the following:

- What are common daily activities or sports activities that would result in increased stress on these muscles, causing them to increase their tension?
- What types of interventions could be used to address hypertonic musculature? What about hypotonic musculature?