1 Basic Concepts in Functional Biomechanics

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1.1 Introduction

Sports-related injuries in pediatric and adolescent athletes are common and provide challenges in determining the best course of care and appropriate criteria for the athletes return to sport. Injuries to adults are also significant in that they can permanently impair function and severely limit activities of daily living. In football, the knee joint is one of the most common sources of both contact and noncontact injuries. Current work in the field of sports medicine aims to diagnose injuries accurately, implement appropriate surgical/nonsurgical treatment solutions and, ultimately, develop the best criteria for early return to sport. In order to best achieve these goals, it is important to understand the normal function of the body in response to daily loading. Functional biomechanics plays a large role in evaluating the body's response to both normal and excessive loading, such as in an injury event.

Biomechanics is an interdisciplinary field that utilizes principles of mechanics applied to the human body in order to improve function through design and development of equipment, as well as analysis of systems and therapies. Applied biomechanics can provide additional knowledge of the effect of loading on the musculoskeletal system and the mechanical responses of the body to these loads, which can be used to assess both normal and abnormal function, as well as predict changes and propose interventions. Additionally,

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basic biomechanics explores the effects of external forces and moments required for movement and, in effect, the consequence of internal loads on soft tissue deformation. This chapter will explore important, sports-related biomechanics concepts and is divided into four different topics: statics, dynamics, mechanics of materials, and applications. Throughout the chapter are examples of applying these biomechanical principles to sports medicine problems and improving return to play following injury.

Functional biomechanics allows one to appreciate the relationships and interactions that various systems, segments, and body parts have with one another that contribute to its ability to perform. These relationships are the foundation for understanding the complexities of human function.

1.2 Statics

Statics analysis of structures evaluates the effect of external loads on a rigid body at rest or in motion at a constant velocity. When applied to the body, statics analysis allows for the determination of the magnitudes and directions of passive, soft tissue forces (e.g., ligaments), muscle forces, and joint reaction forces. In order to perform a statics analysis, a basic principle of physics must be applied.

1.2.1 Newton's Law of Static Equilibrium

Newton's law of static equilibrium states that a body at rest remains at rest and a body in motion tends to stay in motion at a constant speed and in the same direction unless acted on by an unbalanced force. Additionally, every force of action has an opposite and equal reaction in order to maintain this balance. An example of this concept is the ground reaction force. Every time a person places his/her foot on the ground, there is an equal and opposite force exerted from the ground up through the foot. This ground reaction force is transmitted through the kinetic chain of the body (foot, ankle, knee, hip, back, etc.), which loads our joints. As the body prefers a state of equilibrium, drastic changes in the ground reaction force, in terms of magnitude and direction, can lead to potential injury. Similarly, within joints, there are muscles and connective tissues that create a joint reaction force in order to maintain proper joint stability.

When considering a state of static equilibrium, the forces and moments acting on the body must equate to zero (i.e., no motion). The resulting equations for force and moment equilibrium in three dimensions are:

$$\sum Fx = 0; \sum Mx = 0$$
$$\sum Fy = 0; \sum My = 0$$
$$\sum Fz = 0; \sum Mz = 0$$

Forces provide both mobility and stability to the body but can also introduce the potential to deform and injure the body. Healthy tissue can typically withstand the deformations caused by these action and reaction forces; however, injured or diseased tissue may not be able to sustain the same loads required to perform activities of daily living. Statics analysis allows the researcher to represent the complex interactions of the forces and moments acting on the body through the use of vectors and free-body diagrams.

1.2.2 Free-Body Diagrams

To better evaluate a biomechanical system, such as forces or moments being applied to a specified part of the body, free-body diagrams are an effective tool to simplify a complex analysis. Free-body diagrams provide a "snapshot" that represent the interaction between body and environment and allow for visualization and ease of calculation by properly identifying all the forces and moments acting on the body of interest in order to successfully achieve equilibrium.

Force vectors generate the "push and pull" to a system and can originate from internal sources (i.e., muscle forces and joint contact forces) as well as external sources (i.e., friction forces and gravitational forces). A moment (or torque) is a force applied at a distance from a fixed point that tends to cause the rigid segment to rotate.

The magnitude of the moment is a product of the force applied and the perpendicular distance from the applied force to the fixed point. This distance is commonly defined as the moment or lever arm. A larger moment arm requires less force to achieve equivalent angular motion about the axis of rotation. Although a moment can be calculated about any point, typically when performing biomechanical analyses, it is calculated about a joint axis of rotation.

Using the example of a leg extension exercise (Fig. 1.1a) in evaluating the forces about the knee joint, a free-body diagram can assess the change in tension in the quadriceps muscles when adding a weight to the ankle (Fig. 1.1b). The applied forces (both external and internal forces) throughout the system are drawn in order visualize the problem. External forces in the leg extension problem are represented by the weight of the leg and the ankle weight, and internal forces are represented by the force in the quadriceps and the joint reaction force (Fig. 1.1c). The external weight, combined with the weight of leg, causes the leg to experience a flexion moment, while the force from the quadriceps acts in extension in order to balance these external moments (Fig. 1.1d). It is important to note the significant difference in the moment arm between the quadriceps force and the external forces. It is not uncommon for muscle forces to exhibit force magnitudes several times greater than the applied external loads for balance, due to the significantly shortened moment arm of the muscle. Once all of the forces in the free-body diagram have been defined, the laws of static equilibrium are applied to solve for the unknown muscle forces and joint reaction forces.

Reducing the joint reaction force is a common strategy in rehabilitation programs aimed at preventing further joint degeneration in persons with

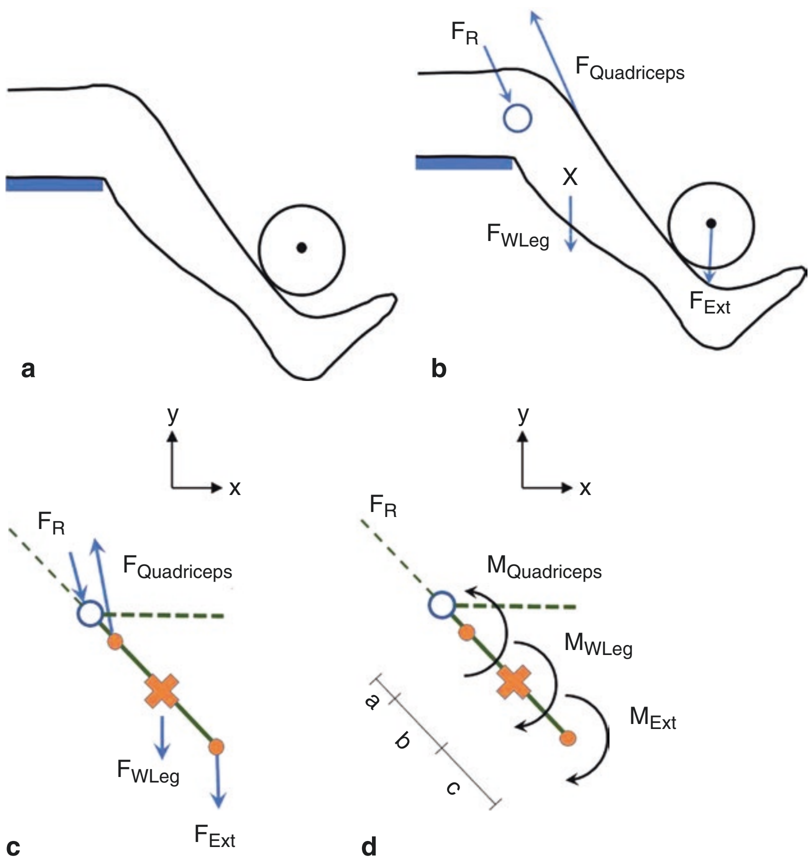

Fig. 1.1 (**a**) Simulation of a person performing a leg extension. (**b**) The ankle weight applies an external force (F_{Ext}) downward in addition to the gravitational force due to the weight of the lower leg (F_{WLeg}). The quadriceps muscle generates a force ($F_{Quadriceps}$) to the lower leg and causes a joint reaction force (F_R) at the knee to keep the joint stabilized. (**c**) A free-body diagram of the lower leg representing each force as an *arrow*, with the *head of the arrow* pointing in the direction of the applied force. (**d**) The quadriceps muscle creates a counterclockwise moment ($M_{Quadriceps}$) to resist the clockwise moments due to the weight of the lower leg (M_{WLeg}) and ankle weight (M_{Ext})

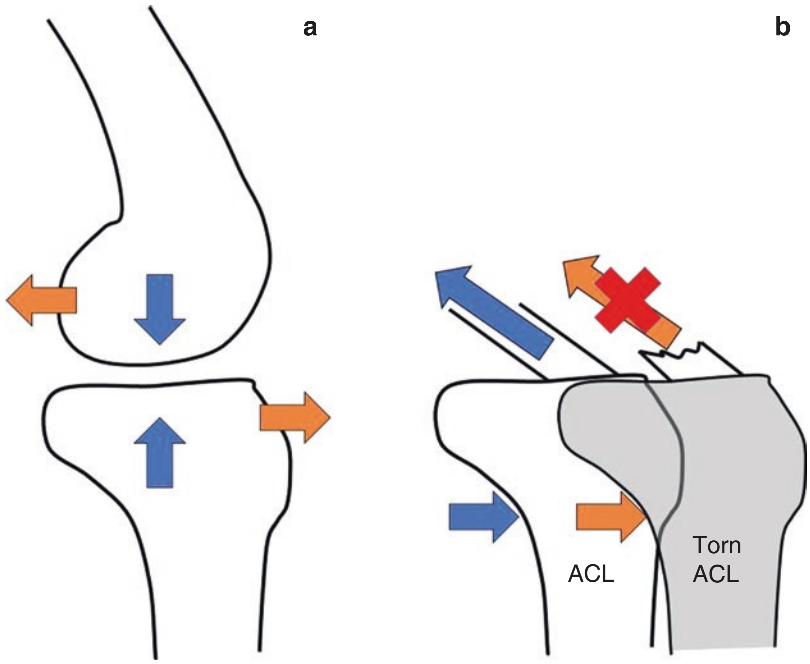

Fig. 1.2 (**a**) At the joint surface, the knee can undergo compressive forces (*blue arrows*), which act in the direction perpendicular to both surfaces, or shear forces (*orange arrows*), which act in the tangential direction to both surfaces. (**b**) Forces applied to the knee joint are transmitted through the ACL (*solid tibia*; *blue arrows*), which resist anterior motion. Rupture of the ACL (*shaded tibia*; *orange arrow*) leads to excessive anterior motion and instability as the forces are unable to be transmitted properly

arthritis. This is commonly achieved by changing the magnitudes of muscle forces or reducing external loads transmitted through the body. For example, a person with medial tibiofemoral osteoarthritis may use a cane on their contralateral side in order to reduce the joint reaction forces in the painful/affected knee joint. When obesity is a factor, a weight reduction program may be implemented to reduce the joint reaction forces. Alternatively in sports rehabilitation, statics analysis can be implemented to improve strengthening programs tailored to best target the proper muscles for the recovering athlete and expedite return to play.

1.2.3 Ligament and Joint Contact Forces

These concepts of statics analysis can be applied not only to whole-body analyses but also at the joint and tissue level. For the typical joint, forces can be related to compression and shear. The tibial plateau and femoral condyles experience compressive forces in the direction perpendicular to each articular surface while standing with the knee in full extension (Fig. 1.2a). Shear forces are experienced in the tangential direction along the surface of interest (Fig. 1.2a), such as when performing an anterior drawer test. Forces can also be transmitted through the soft tissue structures. During a pivoting maneuver, the anterior cruciate ligament (ACL) can become significantly loaded to resist anterior tibial translation and provide stability for the joint. This represents functional loading of the joint and soft tissue. However, after an injury such as an ACL rupture, opposing shear forces cannot be transferred through the ligament, resulting in anterior laxity (Fig. 1.2b).

Fact Box 1 Statics

- Statics analysis assumes state of equilibrium.
- Utilizes Newton's laws of static equilibrium and action-reaction.
- Free-body diagrams aid to simplify complex systems to understand net external and internal forces and moments.

1.3 Dynamics

Dynamics is the study of systems in motion, where the laws of equilibrium have been violated and the net forces and moments of a system do not equate to zero. Analysis of bodies in motion can be subdivided into two subgroups: kinematics and kinetics. Kinematics describes the motion of the bodies without regard to the forces causing the motion. This is typically done by characterizing the geometric and time-dependent aspects of motion. Conversely, kinetics utilizes concepts from kinematics but additionally includes the effects of the forces and moments within a system. Both kinematic and kinetic analyses are commonly performed in sports biomechanics for evaluating motion. This section will primarily focus on kinematics.

1.3.1 Kinematics

As previously stated, kinematics studies motion without regard to the forces and moments causing the motion, which include translations and rotations. Translations are simply the linear motions in which all the points of a rigid body move simultaneously in the same direction and at the same velocity. Rotations are the angular motions of a rigid body along a circular path and about an axis of rotation. During passive knee flexion, the tibiofemoral joint undergoes both linear and angular motions, and both of these motions can occur in multiple planes, such as combined flexion-extension with internal-external tibial rotation.

Motion at an articular surface can be described in terms of three motions that exist resulting from a convex surface moving on a concave surface (Fig. 1.3). Rolling motion occurs when the convex surface rotates. This causes a change in the point of contact for both articular surfaces. A sliding motion is experienced when one articular surface translates across the other with no rotation and progressively changes the point of contact. Lastly, spinning motion occurs at a single point of contact on the fixed surface, where the point of contact changes on the rotating surface and no linear motion occurs. At the tibiofemoral

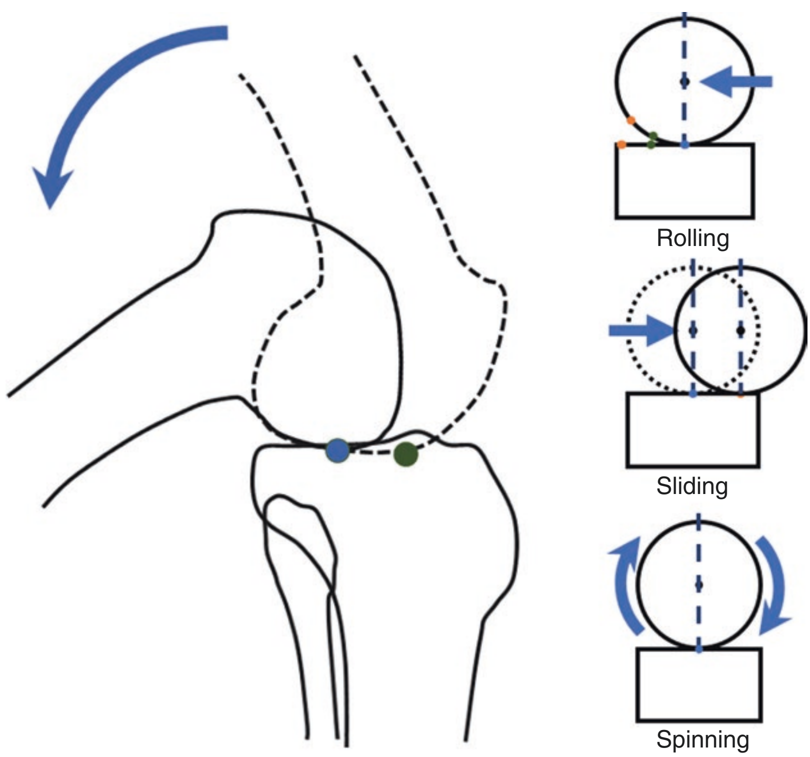

Fig. 1.3 Three fundamental motions that occur between articular surfaces. The point of contact changes on both articular surfaces during rolling motion. The point of contact on the moving surface remains constant during sliding motion. A single point of contact occurs on the fixed surface during a spinning motion. Some joints, such as the tibiofemoral joint, experience up to all three of these motions simultaneously

joint during flexion, the femur (convex surface) will roll in the posterior direction but slide in the anterior direction along the tibial plateau. This type of convex-concave motion encompasses all three motions (rolling, sliding, and spinning) of the femur relative to the tibia through flexion rotation, anterior translation, and external rotation, respectively.

Clinically, it is important to understand these joint motions when performing a pivot-shift maneuver for evaluating the knee joint for stability and assessing potential injury. The pivot-shift maneuver is performed through the combination of compressive and valgus forces, as well as internal rotational torques applied to the lower leg. These forces and torques generate simultaneous sliding (translational), spinning (rotational), and rolling (flexion) motions at the joint surface, which elicit the integrity of the ACL and its ability to stabilize these joint motions. Objective quantification of the pivot-shift maneuver can allow clinicians to track the changes in these joint motions post-surgery and throughout a rehabilitation program in order to make the most informed decision about the athlete's knee state and function. This objective quantification has been an ongoing research topic [1], with studies using inertial sensors [2], electromagnetic tracking sensors [3], and tablet computer software programs [1] to track the complex rolling, sliding, and spinning motion of the knee joint during clinical exams.

In football, noncontact tears of the ACL are common, and injury is 3–4 times higher particularly among female athletes [4]. Studies have shown significant changes in the joint motions after ACL tears in terms of increased rotations (spinning) and joint translations (sliding). The choice of the surgical technique and graft type can significantly impact the restored motion of the joint and, ultimately, the athlete's ability to return to play. For example, it has been shown that drilling a femoral tunnel via an anteromedial portal improves anterior-posterior translation and external femoral rotation during gait compared to transtibial techniques [5]. Additionally, a recent study found significant improvements in rotatory kinematics during gait when using a double-bundle ACL reconstruction compared to a single-bundle ACL reconstruction [6]. It should be noted that neither the single-bundle nor double-bundle ACL reconstructions were able to fully restore rotational kinematics during gait after 14 weeks of postoperative physiotherapy. In order to improve outcomes from these surgeries, it is important to understand the forces within structural tissue, such as ligaments, and how the properties of the tissue can affect its function.

Fact Box 2: Kinematics

- Kinematics studies motions without regard to the forces and moments causing motion.
- Motion of the human body can occur simultaneously in multiple planes.
- Understanding and measuring changes in joint motion are important for developing appropriate treatment strategies and developing criteria for return to sport.

1.4 Mechanics of Materials

Mechanics of materials is the study of forces and their effects on motion within rigid and deformable systems. When examining the behavior of solid bodies, such as the forces acting on joint limbs and their resulting motions, rigid body mechanics may apply. When examining the effect of forces and motions on the internal stresses of the body, deformable mechanics may apply. Both rigid body mechanics and deformable mechanics provide information about the behavior of the body and tissue structures (i.e., ligaments) when exposed to loads, particularly when these loads can lead to injury.

1.4.1 Rigid Body Mechanics

Rigid body mechanics assumes that any deformations caused by forces acting on a body are negligible. While this assumption can aid in simplifying biomechanical analyses, it should be noted that no

Table 1.1 Structural properties of common ACL graft choices for reconstruction

	Native ACL	Hamstring tendon [7]	Patellar tendon [8]	Quadriceps tendon [9]
		Doubled ST + GT	10 mm graft	
Load-to-failure (N)	2160	2831	2977	2353
Stiffness (N/mm)	242	456	455	326

ST semitendinosus tendon, *GT* gracilis tendon

material in the human body can truly be considered a rigid body, as all tissues undergo some degree of deformation. Therefore, it is important to clearly understand when the rigid body assumption is applicable. If one material is much stiffer than the other or the deformations experienced by a body are much smaller than the translations or rotations of that body, then the rigid body principle can be applied. Branches of statics and dynamics are forms of analyses that utilize the principle of rigid body mechanics. For example, when analyzing gait, the translations and rotations of the lower extremity will be much greater than any deformations experienced by the segments of the lower extremity, allowing it to be treated as a rigid body. This assumption is also applicable when performing mechanical testing of a joint complex, such as the femur-ACL-tibia complex, where the bones can be considered a rigid body since it is much stiffer than the ligament tissue. Traditional approaches to evaluate both static and dynamic systems assume that each object in the system is a rigid body. The following section better accounts for the realistic deformations that occur in the musculoskeletal system as a result of loads applied at the tissue level. This includes both soft (articular cartilage, tendons, ligaments, capsular tissues) and hard (bone) tissues.

1.4.2 Structural Properties of a Complex

Mechanics of materials when applied to a structure that may incorporate multiple materials or tissue types (termed complex) can provide information about the structural properties of the complex when exposed to different forms of loading (i.e., tensile, compressive, shear). For example, the structural properties of the femur-ACL-tibia complex can be determined in response to a tensile load to assess its load-elongation behavior. To do this, a tensile force is applied to the bone-ligament-bone complex, causing the tissue to become stretched until the complex ruptures. While loading is applied, the corresponding increase in length in the complex is measured. The resulting nonlinear load-elongation curve that is typical of biologic soft tissues provides information about the structural properties of the tissue complex, such as its stiffness and ultimate load at failure. These parameters are important to define for healthy tissue as, clinically, they can factor into the graft choice for a reconstruction surgery. Table 1.1 clearly shows the differences between the structural properties of different tissue complexes that are commonly used as graft types for ligament reconstruction [1]. These properties can significantly affect the function of the joint and should be carefully considered prior to reconstruction.

In the biomechanics field, it has been well established that factors such as age, injury, and healing can significantly affect the structural properties of a bone-ligament-bone complex as well as the failure mode of the complex [10, 11]. Tensile failure tests in a rabbit femur-medial collateral ligament (MCL)-tibia complex demonstrated significant increases in tensile strength as a result of maturation. Additionally, failure modes in these models progressed from tibial avulsions in the younger tissue to failure in the midsubstance of ligament [11]. It has also been shown in a recovering femur-MCL-tibia complex that the recovering tissue complex exhibits significantly decreased stiffness (53%) and ultimate load (29%) compared to an uninjured joint state [10]. These classic studies have provided evidence as to how the structural properties of tissue complexes change as a result of aging, injury, and throughout recovery. These concepts are important when evaluating the rehabilitation choice (surgical vs. nonsurgical) for an injured athlete and the timeline for return to play.

1.4.3 Mechanical Properties of Tissue

It is also important to understand the mechanical response of an individual tissue or material, which is independent of specimen geometry, by using normalized load and deformation parameters. Measuring the mechanical properties of tissues, such as ligaments, can be used to evaluate the quality of the tissue when making comparisons between normal, injured, and healing states and are represented by the stress-strain relationship. Stress is defined as the amount of force applied per unit area and is one of the most basic engineering principles. Strain is considered as a dimensionless measure of the degree of deformation in the tissue, which is defined as the change in length per unit length. Stress-strain relationships are obtained experimentally during tensile, compressive, or shear loading of the excised tissue.

A typical stress-strain curve for biologic tissues consists of four distinct regions (see Fig. 1.4). The first noticeable region is a nonlinear toe region (region 1), where significant stretch

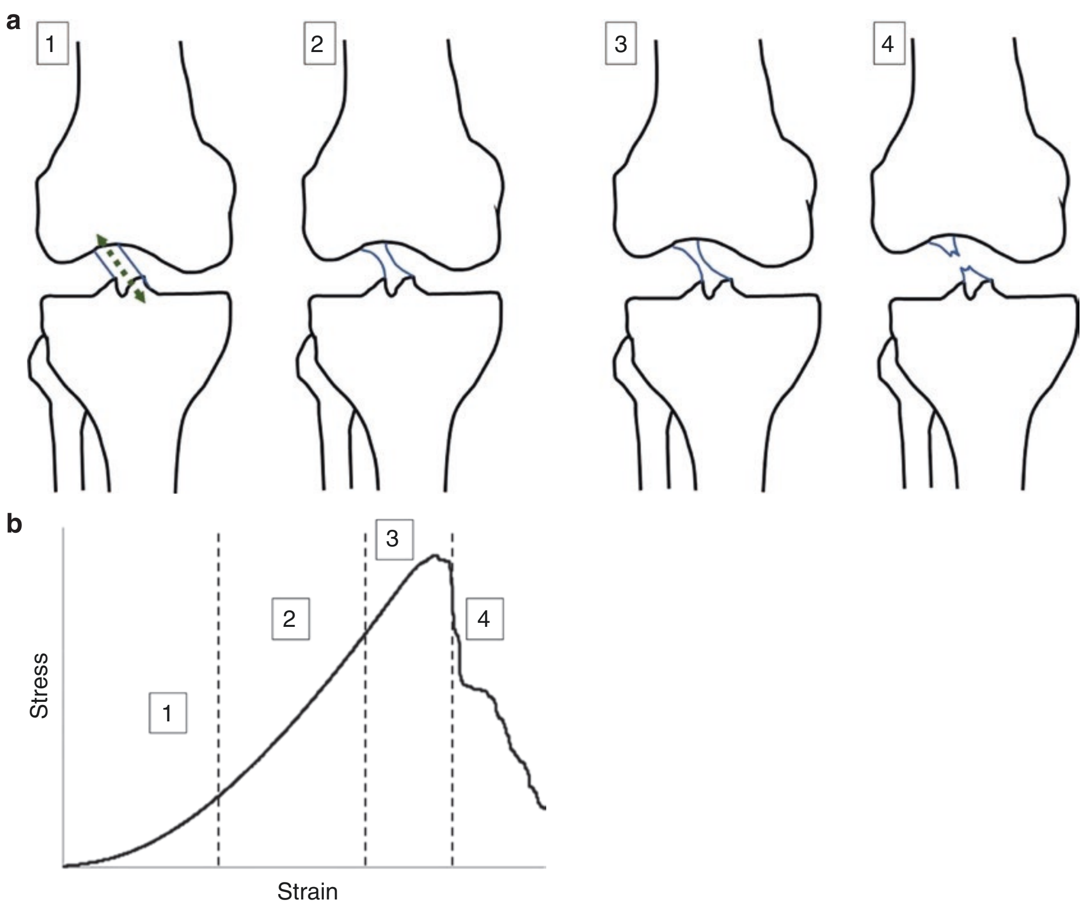

Fig. 1.4 (**a**) Conceptual example of load-to-failure test in the ligament consisting of four regions of loading: (*1*) initial recruitment of the collagen fibers; (*2*) increased load bearing through the ligament; (*3*) continued loading and deformation of the ligament; (*4*) ultimate rupture of the ligament. (**b**) Stress-strain curve of the ligament substance that characterizes the mechanical properties during a load-to-failure test. Regions *1*, *2*, *3*, and *4* correspond to the toe region, linear region, partial failure of the material, and complete rupture of the material, respectively

of the material occurs with a minimal increase in stress. This is a direct result from stretching of the crimped collagen fibrils as the fibers are being drawn taut in the material and before significant tension occurs within the material. Strain becomes linearly proportional to stress in region 2, and the slope of the curve in this region can be calculated to determine the tangent modulus of the tissue. The tangent modulus defines the threshold of the material beyond which permanent deformation (plastic) can begin to occur. The area under the curve within this linear region can be referred to as the strain energy density. This region is commonly reached during daily activities, where the tissue undergoes a form of "elastic" deformation, meaning the tissue will return to its original length or shape upon unloading. Furthermore, the energy used to deform the tissue is released when the applied stress is removed. When the tissue experiences abnormally large levels of strain, the tissue undergoes only a marginal increase in corresponding stress (region 3). It is at this point that the tissue begins experiencing microscopic failures. The area under this region of the curve represents plastic deformation energy. Once the tissue undergoes this amount of deformation, the tissue does not recover and return to its original state in its entirety upon release of the deforming stress. If the tissue continues to deform, it will eventually experience complete failure (region 4). Common mechanical properties of tissues derived from mechanical tests include modulus, ultimate strength, ultimate strain, and strain energy density. These properties describing the mechanical properties of tissue can be used to evaluate injured and healing states.

Clinically, the mechanical properties of tissue can be significantly influenced by not only injury but also during recovery [10, 12]. The detrimental effects of disuse injuries have been well documented. Specifically, immobilization of tendons and ligaments can significantly reduce the mechanical properties of the tissue as well as the mass of the structure [12]. Additionally, the long-term effects of disuse have been shown to require up to 12 months of time for complete recovery of ligament strength parameters [13]. Classic studies have had a major impact on the decision hierarchy for return to play that has evolved in sports medicine/sports traumatology over time.

1.4.4 Viscoelasticity

Viscoelastic materials exhibit both solid-like characteristics, such as strength and elasticity, and fluidlike characteristics, like flow, which are dependent on time and rate of loading. Most tissues within the musculoskeletal system demonstrate at least some degree of viscoelasticity. When plotting a load-elongation curve during a nondestructive tensile test, unloading of a viscoelastic material will leave a region between the loading and unloading curves known as hysteresis, a common viscoelastic property of all biologic tissues (Fig. 1.5). This region of hysteresis is created due to energy lost (heat) when unloading the material. Preconditioning with repeated loading and unloading of the tissue decreases this area of hysteresis and maximizes elongation of the tissue, which is why athletes precondition the tissue in their bodies to maximize performance by completing repetitive stretching activities prior to competition.

A viscoelastic material experiences two common phenomena known as creep and stress relaxation. Creep describes a progressive increase in elongation of a material when exposed to a constant load over time (Fig. 1.6a). Simply, creep can be considered the tendency of

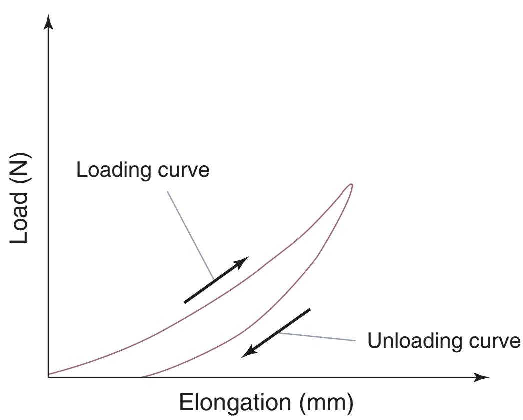

Fig. 1.5 Load-elongation curve of a biological soft tissue in response to an applied tensile load. The area between the loading and unloading curves represents the energy absorbed by the tissue during this loading regimen, which is known as hysteresis

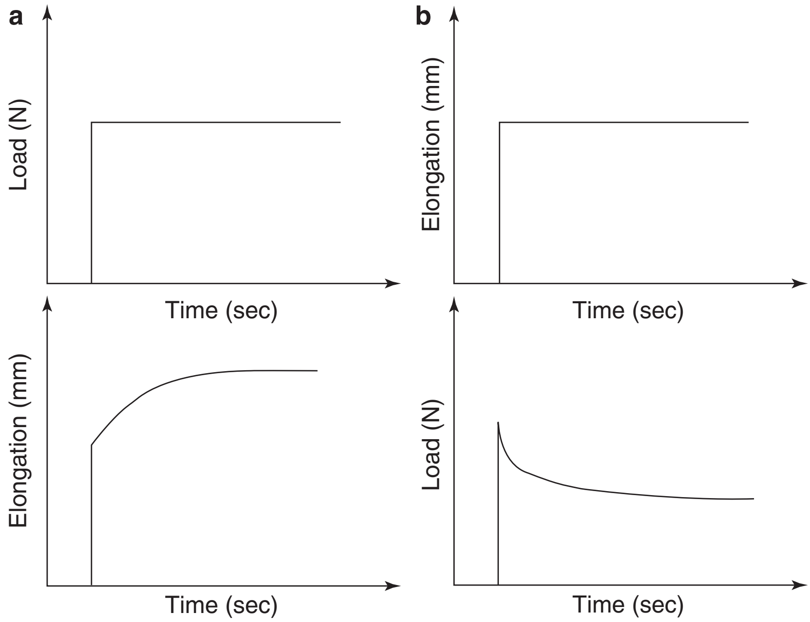

Fig. 1.6 Viscoelastic phenomena exhibited by biologic tissues include (**a**) creep response due to a constant applied load and (**b**) stress relaxation response due to a constant applied elongation over some time

a material to move or deform in response to a constant stress. Conversely, with stress relaxation, a decrease in load occurs over time upon application of a constant elongation (see Fig. 1.6b). Stress relaxation is the phenomenon that occurs in a material to relieve stress under a constant elongation due to the fluidlike characteristic of viscoelasticity. For both creep and stress relaxation, the tissue will reach a state of equilibrium after a period of time.

A practical observation of creep in the clinic is demonstrated when the length of a graft from a tendon or ligament reconstruction inevitably increases from its original length. Applying both tension and circumferential compression of hamstring ACL grafts has been shown to elongate the graft while reducing the average diameter by as much as 0.7–0.8 mm [14]. Foregoing this preconditioning could potentially lead to instability due to creep-related elongation over time as well as a mismatch of graft diameter within the bone tunnel. This is clinically relevant as surgeons may be able to reduce the size of their bone tunnel for operation, thus reducing the amount of bone removal.

Fact Box 3: Mechanics of Materials

- Mechanics of materials studies forces and their effect on motion.
- Mechanics of materials can be used to understand structural properties of whole tissue complexes and mechanical properties of individual tissue, such as ligaments.
- Biomechanical properties are important for understanding changes in the native tissue when injured, as well as important to choosing the best surgical graft for repair.

1.5 Applications

The concepts presented throughout this chapter provide a methodology to understand and quantify how the human body performs activities of daily living. This information can be used in orthopedic sports medicine to improve injury diagnosis, advance surgical reconstruction techniques, and monitor rehabilitation programs to aid the player in return to play.

1.5.1 Injury Diagnosis

Functional biomechanics can be used when evaluating and improving the diagnosis of potential injuries by conceptualizing the forces and moments (i.e., free-body diagrams) applied during an activity and identifying the appropriate tissues supporting these loads. For example, understanding the magnitude and direction of the loads applied during an anterior drawer test can aid in identifying the state of the ACL, as it is the primary restraint to anterior tibial load. Applications of biomechanics has led to the development of tools and devices capable of providing objective quantification of the pivot-shift test, which can be used to identify the function and injury state of the ACL. Improving the accuracy and clinical utility of these applications will one day allow athletic programs to implement these tools in establishing a baseline measurement of each athlete's joint motions upon entering the program, thus improving diagnosis when an athlete has suffered an injury.

1.5.2 Surgical Reconstruction

The purpose of surgical reconstruction is to restore function by replacing nonfunctional tissue with a replacement, such as a graft or other implant. However, in order to adequately restore function, it is important to understand the mechanics and biomechanical properties of the original tissues and whatever material is being used to replace them. Any materials being used to replace natural tissues, such as tendons or ligaments, must be able to function under the same range of motion experienced by those connective tissues while maintaining adequate strength and stiffness. For example, the ACL is part of a complex loading environment experiencing both shear and longitudinal stresses during normal gait. The primary function of the ACL is to resist anterior translation of the tibia with respect to the femur. The graft choice for ACL reconstruction must match the stiffness of the original tissue in order to sufficiently resist anterior translation of the tibia due to the forces and moments experienced during gait. However, the graft must also be compliant enough to allow for the normal range of knee motion. Time-dependent viscoelastic properties of the graft must also be taken into account, since any amount of creep occurring after the surgical reconstruction can result in increased translations at the joint.

1.5.3 Improving Rehabilitation

Principles of biomechanics are important to consider when developing rehabilitation programs for individuals after injury and/or surgery. Statics analysis can aid the clinician in developing the best rehabilitation treatment exercise that will optimize the muscular/soft tissue activity for earlier recovery.

Designing a rehabilitation protocol that maintains range of motion and muscle strength is advantageous to the long-term healing of the patient. However, overaggressive rehabilitation could lead to failure of the repair. For example, it is common for limited weight bearing and range of motion exercises to be prescribed within the first week after an ACL reconstruction. These exercises are meant to provide functional levels of preconditioning in order to minimize the viscoelastic effects within the graft and prevent degenerative changes associated with immobilization. Knowledge of normal biomechanical properties can be used to design a regimen that would maintain motion and muscle tone while also protecting the graft used for repair, which would ultimately expedite recovery.

Conclusions

Despite the advances in diagnostic tools, surgical treatments, rehabilitations techniques, and injury prevention programs, ligament tears, particularly of the ACL, are still common in sports. The field of biomechanics will continue to explore each of these aspects of sports injury in order to improve existing treatment methods or develop newer modalities to prevent injury and expedite the players' return to play. This chapter introduced the basic terminology and concepts of statics, dynamics, and mechanics of materials using examples relevant to sports medicine and return to sport. The concepts discussed provide a guideline to approaching both static and dynamic systems to estimate unknown forces and moments experienced on the body by use of a free-body diagram. A description of biologic materials within the musculoskeletal system has been presented. Although biomechanics has great depth and breadth to it, the concepts presented should allow the reader to begin making the link between sports medicine and biomechanics.

Take-Home Message

- Newton's laws of motion are used to describe the relationship between the forces applied to the body and the results of those forces on human motion.
- Statics analysis evaluates the external effects of forces on a rigid body at rest or during motion with a constant velocity.
- Dynamic analyses evaluate bodies in motion and can be divided into two subgroups: kinematics (motion without regard to forces and moments) and kinetics (includes the effect of forces and moments).
- Mechanics of materials can be utilized to evaluate biologic materials, including both soft and hard tissues, under different forms of loading and characterize the tissue based on two categories: structural properties of whole tissue complexes (i.e., bone-ligament-bone) and mechanical properties of tissue (i.e., ligaments).
- Structural properties of tissue complexes provide the mechanics of a structure that incorporates multiple materials or tissue types and the response of this complex to tensile, shear, and compressive loading.
- Mechanical properties of tissue are evaluated by the stress-strain relationship and can be used to evaluate the quality of the tissue when making comparisons between normal, injured, and healing states.
- Understanding the biomechanical properties of tissue is important for improving injury diagnosis, generating new therapies through surgical reconstruction, and designing functional rehabilitation strategies.

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