Journal of
Functional Morphology and Kinesiology

Review

Anatomy and Physiology of Knee Stability

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Received: 28 June 2017; Accepted: 20 September 2017; Published: 24 September 2017

Abstract: Knee instability has been the focus of large number of studies over the last decade; however, a high incidence rate of injury still exists. The aim of this short report is to examine knee joint anatomy and physiology with respect to knee stability. Knee joint stability requires the integration of a complex set of anatomical structures and physiological mechanism. Compromising any of these structures leads to destabilisation and increased risk of injuries. This review highlights the structure and soft tissue of the knee that contribute to its stability and function. This introduction is part of the Journal of Functional Morphology and Kinesiology's Special Issue "The Knee: Structure, Function and Rehabilitation".

Keywords: knee; anatomy; stability

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1. Introduction

Joint instability is a problem from which both athletes and non-athletes suffer, with one of the most common sources of instability being associated with the knee joint. Knee instability has a high incidence rate and has been extensively studied over the last decade. For example, one prospective cohort study conducted over seven consecutive professional football seasons found that injuries due to knee instability was second only to thigh strains (23%), and 18% of all injuries were sustained at the knee joint [1]. However, it is not only professional athletes at risk of these injuries, as Loes, Dahlstedt, and Thomée [2] reported that knee injury accounted for 15% to 50% of injuries related to 12 different sports during a longitudinal seven year trial of recreational male and female exercisers. Knee instability is a problem affecting both young and old individuals, as those aged over 65 years have been reported to suffer from one to three incidences of falls due to several factors, including self-reported knee instability [3]. It affects a varied population, including professional athletes [4,5], older adults, and recreational exercisers [6]. The impact of knee instability can be severe, and may lead to an increased risk of falls [3] and a long period of rehabilitation [7]. These consequences of knee instability increase the cost to health care systems [8,9]. Loes, Dahlstedt, and Thomée [2] concluded that knee injuries accounted for a high proportion of the costs in the medical treatment of sport injuries. Many countries have health care systems focused on value-based care, which are systems focused on understanding the cost drivers, implementing high-value therapies [10], and improving methods and/or techniques to assess knee instability and rehabilitation therapies that could potentially reduce the health care costs associated with knee injury [11].

A comprehensive understanding of the anatomy and physiology of the structures of the knee is necessary for accurate diagnoses and informed decisions regarding treatment plans. An overview of the physiology of knee stability, mechanics, and hamstring stretch reflex will be presented in this review. The aim of this report is to review the present knowledge and provide an overview on the structure and function of the knee joint, which will provide basic background knowledge to the subsequent articles in the journal's Special Issue "The Knee: Structure, Function and Rehabilitation".

2. Anatomy of Knee Stability

2.1. Bony Structures

The knee is a complex modified hinge joint with the greatest range of movement in flexion and extension about the sagittal plane, as well as varus and valgus rotation about the frontal plane. Also, it facilitates the medial rotation at the end of the knee flexion and the lateral rotation at the terminal extension of the knee both at the transverse plane. The knee maintains stability and control during a variety of loading situations. It consists of two bony articulations; the articulation between the femur and tibia bears most of the body weight, while the articulation between the patella and femur creates a frictionless transfer over the knee of the forces generated by contraction of the quadriceps femoris muscle [12]. The knee consists of two main joints: the femorotibial joint and the patellofemoral joint, which allow the knee to move in three different planes (sagittal, transverse, and frontal). This offers a six degrees of freedom range of motion, including flexion, extension (sagittal planes), internal, external rotation (transverse plane), varus, and valgus stress (frontal plane). The position of the knee between the two longest lever arms of the body, the femur and tibia, and its role in weight bearing renders it susceptible to injuries.

2.2. Knee Ligaments, Cartilage, and Bursae

The knee is stabilised by both primary stabilisers and secondary stabilisers. Primary knee stabilisation is achieved through knee ligaments, while muscles around the knee play a secondary role, although both work congruently to help the knee function reliably. This is achieved through involuntary work as muscles are connected to tendons in order to be dynamically reinforced and contracted during motion, which is when ligaments are at risk and need the assistance provided through muscular force. The intercondylar articular cavity of the knee is enclosed by a fibrous joint capsule.

Ligaments are fibrous bands of tissue that connect bone to bone and provide support to joints. The knee is reinforced by two collateral ligaments, one on the medial side and another on the lateral side, as well as two stronger ligaments (the cruciate ligaments) that prevent excessive anterior, posterior, varus, and valgus displacement of the tibia in relation to the femur. The patellar ligament attaches proximally to the apex of the patella and distally to the tibial tuberosity, and is the inferior continuation of the quadriceps femoris tendon. Other ligaments, such as the transverse, arcuate popliteal, oblique popliteal, anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), lateral collateral ligament (LCL), and popliteofibular ligament all act as knee stabilisers. All provide stability in a specific direction and play a role in joint proprioception through their cutaneous receptors. The ACL primarily resists anterior and rotational displacement of the tibia relative to the femur, while the PCL prevents posterior displacement. The MCL provides stability to the medial aspect of the knee, preventing excessive valgus stress during external rotation of the knee, becoming tight during extension and external rotation, and loose during flexion and internal rotation. The LCL runs from the femur to the fibula to stabilise the lateral aspect of the knee, preventing excessive varus stress and external rotation at all positions of knee flexion [13,14]. The popliteofibular ligament acts as a static restraint to the external rotation of the tibia on the femur and to posterior tibial translation. There are additional small ligaments that surround the knee and aid in maintaining overall knee stability, including the capsular ligament, anterolateral ligament, arcuate ligament, and posterior oblique ligament.

The ACL is considered the main stabiliser of the knee, contributing to about 85% of the knee stabilisation, and enabling smooth and stable flexion and rotation of the knee [15]. As a result, it is the most frequently injured and has been the major focus of studies in recent decades, and its importance and fundamental role in knee stability has led to a substantial body of work investigating its anatomy [16,17], physiology [18,19], biomechanics [20–22], assessment [23–27], risks [28,29], and rehabilitation [30–34]. The ACL is supplied by branches of the genicular artery, which consists of two bundles, the anteromedial and posterolateral. The anteromedial bundle forms the shortest band and is tense in flexion and lax in extension, while the posterolateral bundle is taut in extension and lax in flexion. The ACL experiences the least strain between 20° to 30° under normal knee motion; consequently, assessment of the ACL at 20° to 30° of knee flexion is preferable in order to accurately assess the stiffness of the ligament [35]. During early rehabilitation of an ACL injury, knee flexion should be set at 60° and beyond, as quadriceps muscle has its least degree of strain at 60° and beyond of knee flexion [21].

The ACL is innervated by branches of the tibial nerve, and Schutte et al. [16] found three mechanoreceptors and nerve endings along the course of the ACL, each with a specific function. There are two Ruffini receptors which sub-serve speed and acceleration (sensitive to stretching) and one Pacinian receptor which signals motion. Furthermore, a small number of free nerve endings have been identified in the ACL that are responsible for pain.

Two fibrocartilaginous menisci, medial and lateral, are positioned between the medial and lateral femoral condyles and the tibia, which accommodate changes in the shape of the articular surfaces during activity. They provide a good 'seat' on the tibial condyles for the corresponding femoral condyles. Articular cartilage covers both the femoral and tibial condyles and provides a frictionless surface that allows joint movement. They also act as shock absorbers for the body load and dynamic movements. The lateral menisci are much more mobile than the medial menisci, and this is reflected by the higher rate of medial side injuries [19]. This may be due to the fixed meniscus being less able to compensate for joint forces and rotations during movement. Nonetheless, it provides greater restraint to anterior translation of the tibia on the femur. Injury to the lateral meniscus is more devastating than a medial meniscus injury, leading to instability of the lateral side of the knee, and the rapid development of osteoarthritis, hence making its rehabilitation more challenging than medical meniscus injury [36].

The knee has four bursae, which are fluid-filled cavities located at tissue sites that facilitate movement of the tendons and skin over the joint. They are filled with synovial fluid and help in reducing friction between adjacent moving structures, five of which are located at the frontal aspect of the knee, with another four at the lateral side and another five on the medial side of the knee joint. They are distributed around high-motion areas to ensure smooth, friction-free movement. A common site of bursitis is at the deep infrapatellar bursa due to its vital role in preventing friction between the patellar tendon and the tibia. Bursitis has no direct structural effect on stability, but one could argue that inflammation causes a behavior effect on stability [37]. Information about its anatomic location can help the physician to decide a proper diagnosis to include in the differential diagnosis of anterior knee pain.

2.3. Muscles Acting on the Knee Joint: Their Innervation and Vascularity

The secondary stabilisers of the knee joint are all the muscles surrounding the knee alongside the hip muscles and the gastrocnemius muscle. Although their primary function is to produce motion for all the 6 degrees of freedom of the knee, they also interact with the neuromuscular system to control knee motion, and hence play a vital role in knee proprioception.

The majority of the muscles around the knee that are monoarticular act to primarily mobilise and secondarily stabilise the knee. Some of these muscles have additional actions at the hip joint (biarticular) where they have dual actions at both the knee and hip. The anterior aspect of the knee consists predominantly of the quadriceps muscles, namely the rectus femoris (biarticular), vastus lateralis (monoarticular), vastus medialis, and vastus intermedius, and the primary function of these muscles is to extend the knee joint.

The posterior aspect of the knee consists of the biceps femoris (biarticular), semimembranosus (monoarticular), and semitendinosus (monoarticular), which form the hamstring group of muscles which function as knee flexors. The plantaris muscle and the medial and lateral heads of the gastrocnemius muscle are also part of the posterior musculature of the knee. The soleus muscle also resists anterior translation of the knee. These act primarily as plantar flexors and secondarily as knee flexors.

The medial musculature of the knee consists of the sartorius and gracilis muscles, which both aid in knee flexion. In addition, the semitendinosus acts as a medial rotator of the knee. Finally, the musculature of the lateral aspect of the knee consists of the iliotibial band and the popliteus muscles. The primary function of these muscles, along with the semimembranosus and semitendinosus, is to flex the knee, but these muscles also act as hip extensors. The biceps femoris acts as a lateral rotator of the knee, as does the semimembranosus muscle, whilst the tensor fasciae latae and iliotibial band act as lateral stabilisers of the knee, and the popliteus muscle rotates the knee both laterally and medially.

The knee is innervated by branches of the obturator, femoral, tibial, and common fibular nerves. Each structure within the knee is innervated by a shared or a specific nerve. The vascular supply to the knee consists of a network of many arteries. The genicular branches of the femoral and popliteal arteries, the circumflex fibular arteries, and the recurrent branches of the anterior tibial artery, all supply blood to the knee. The blood supply of the medial and lateral knee cartilage (menisci) differs. The medial menisci receive a greater blood supply than do the lateral menisci and consequently, injuries involving the lateral menisci require longer rehabilitation. Furthermore, the lateral menisci are much more mobile than are the medial menisci, and this is reflected by the higher rate of medial side injuries [19]. This may be due to the fixed meniscus being less able to compensate for joint forces and rotations during movement. Nonetheless, it provides greater restraint to anterior translation of the tibia on the femur. During rehabilitation, injury to the lateral meniscus is more devastating than a medial meniscus injury, leading to instability of the lateral side of the knee, and the rapid development of osteoarthritis [36]. Table 1 illustrates summary of structures contributing knee joint stability.

Table 1. Summary of structures contributing knee joint stability.

Type of Stability	Type	Innervation	Origin	Insertion	Action
Posterior-Anterior Stability					
Posterior cruciate ligament	Primary	Tibial n.	Anterior-lateral aspect of medial femoral condyle	Posterior slope of tibial plateau	Restrict PA translation of tibia on femur Tibial external rotation
Rectus femoris	Secondary	Femoral n.	Anterior inferior iliac spine	Patellar tendon	Leg extension Hip flexion
Vastus lateralis	Secondary	Femoral n.	Greater trochanter, intertrochanteric line of femur	Patella and tibial tuberosity	Leg extension
Vastus medialis	Secondary	Femoral n.	Medial aspect of femur	Quadriceps tendon	Leg extension
Vastus intermedius	Secondary	Femoral n.	Anterior-lateral aspect femur	Quadriceps tendon	Leg extension
Anterior-Posterior Stability					
Anterior cruciate ligament	Primary	Tibial n.	Posterior-medial aspect of lateral femoral condyle	Anterior aspect of tibial plateau	Restrict AP translation Anterolateral rotation of tibia on femur
Biceps Femoris					
Long head	Secondary	Tibial n.	Ischial tuberosity Femoral shaft	Head of fibula	Leg flexion Leg lateral rotation Hip extension
Short head	Secondary	Common fibular n.	Ischial tuberosity Femoral shaft	Head of fibula	Leg flexion Leg lateral rotation Hip extension
Semimembranosus	Secondary	Sciatic n.	Ischial tuberosity	Medial condyle of tibia	Knee flexion Hip extension
Semitendinosus	Secondary	Sciatic n.	Ischial tuberosity	Pes anserinus (tibia)	Knee flexion Hip extension
Plantaris	Secondary	Tibial n.	Lateral supracondylar ridge of femur	Tendo calcaneus	Ankle plantarflexion Knee flexion
Gastrocnemius	Secondary	Tibial n.	Lateral and medial condyle of femur	Calcaneus	Ankle plantarflexion Knee flexion
Sartorius	Secondary	Femoral n.	Anterior superior iliac spine	Pes anserinus (tibia)	Hip flexion Hip abduction Hip lateral rotation Knee flexion

Table 1. *Cont.*

Type of Stability	Type	Innervation	Origin	Insertion	Action
Varus/Valgus Stability					
Medial collateral ligament	Primary	Femoral n.	Medial femoral epicondyle	Periosteum of proximal tibia	Restrict valgus stress Restrict tibial anterior-medial rotation
Lateral collateral ligament	Primary	Common fibular n.	Lateral femoral epicondyle	Posterior to anterior point of fibular head	Restrict varus stress Restrict tibial posterior-medial rotation
Popliteus	Secondary	Tibial n.	Lateral femoral epicondyle	Posterior surface of tibia	Tibial medial rotation (femur fixed) Femoral lateral rotation (tibia fixed)
Tensor fasciae latae	Secondary	Gluteal n.	Iliac crest	Iliotibial tract	Hip flexion Knee mediolateral rotation

Abbreviations: n = nerve, AP = Anterior-posterior, PA = Posterior-anterior.

3. Physiology of Knee Stability

3.1. Terminology for Describing Knee Instability

As Noyes, Grood, and Torzilli [38] reported in their review, in order to better understand the condition of a knee, it is important to clarify the definition of the terms commonly used to describe its motion. There is inconsistency within the literature over the terminology used to characterise knee instability; for example, the terms instability, laxity, and disability tend to be used incorrectly. The most commonly accepted definitions that come from consensus opinion will be reported in this review. Laxity is defined as excessive joint movement within the constraints of its ligaments, whilst knee instability is defined as the inability to maintain a single leg stance because the joint subluxes due to pathological laxity, and disability is defined as instability that interferes with the required function of the knee. Thus, each of these terms describes a specific situation.

3.2. Afferent Feedback

Sensory receptors are classified either by the type of stimulus to which they respond (e.g., mechanoreceptors, nociceptors, chemoreceptors, etc.) or by their location (e.g., exteroceptors, interoceptors, or proprioceptors). The major classes of sensory receptors that provide afferent feedback contributing to knee stability are mechanoreceptors and nociceptors; where proprioceptors can be considered a sub-classification of mechanoreceptors. All of these receptors project to spinal motor neurons, spinal interneurons, and several supraspinal structures. As a result, afferent feedback from these receptors provides the spinal and supraspinal neural networks information about joint position, movement, and nociception. The receptors generally considered to provide the central nervous system with afferent feedback important for knee stability include Ruffini endings, Pacini corpuscles, free nerve endings, Golgi tendon organs, and muscle spindles (types I and II). Pacinian corpuscles are sensitive to the micro-vibrations that occur during knee movement and, in the cat, respond transiently to joint movement in any direction [39]. Ruffini endings are present in a variety of tissues and, in the ligaments of the knee, respond to tension; they contribute to knee stability by detecting the limits of angular excursion [40]. Proprioceptors, i.e., muscles spindles and Golgi tendon organs, are located in the muscle and aponeurosis, respectively. Free nerve endings are small diameter unmyelinated nociceptor fibres found throughout the connective tissue. Spindles provide information about joint speed (spindle type I endings) and joint position (spindle type II endings), whereas Golgi tendon organs act as force sensors. However, there remains some controversy about the types and precise location of mechanoreceptors in human ligaments [41]. For example, Cabuk and Cabuk [42] examined a small sample of human cadaver ligaments and tendons to determine the presence and distribution of mechanoreceptors. The reported that free nerve endings followed by Ruffini endings and Golgi-like endings were the most prevalent type of mechanoreceptors. In contrast to animal studies, they did not find evidence of Pacini corpuscles in their samples.

These proprioceptive fibres, together with the ligaments and muscles, combine to create reflex arcs that play a vital role in knee stability [43,44] by providing feedback between the central nervous system (CNS) and the joint. The CNS (cerebellum) receives neurologic input from joint position sensors, muscles spindles, and the joint capsule, and this generates neurological feedback from the cerebellum in response to joint movement which aids in maintaining joint stability [45]. However, this protective mechanism can fail during movements that exceed the structural limits of the joint. For example, an external traumatic force or sudden unpredicted movements can exceed the ability of the proprioceptive arc to respond, and consequently, injury may occur. The resistance of the knee to injury depends on the strength of both its primary and secondary stabilisers, and the proprioceptive efficiency of the structures around the knee [46]. Moreover, knee joint osteoarthritis can add to the equation, leading to potential increases in disabilities and pain sensation of the patients [47].

As mentioned in Sections 2.2 and 2.3, ligaments, muscles, and proprioceptive mechanisms all act to stabilise the knee. Research suggests that an ACL-hamstring reflex exists and plays a role in knee stability [43,44]. Beard et al. [48] showed that ACL-deficient knees had a longer hamstring contraction latency than non-injured knees (99 ms and 53 ms, respectively), yet Jennings and Seedhom [49], when replicating the work of Beard et al. [48], found no significant difference between hamstring contraction latency in ACL-deficient knees and non-injured knees. However, Jennings and Seedhom [49] recruited participants who had undergone arthroscopy sometime in the previous 10 years without reporting if the participants in the ACL-deficient knee group had undergone any proprioceptive training, while Beard et al. [48] recruited participants within 18 months of arthroscopy and none of their participants had received any proprioceptive training. This difference in participant populations may have resulted in the disparity in the results obtained from these two studies, as sensorimotor training may enhance neural drive and subsequently improve joint proprioception [50–52], thereby reducing the delayed onset of the ACL-hamstring reflex. Friemert et al. [53] reported that 10 out of 10 trials (100%) elicited stretch reflex during an intraoperative direct mechanical stimulation of the anterior cruciate ligament. On the other hand, Abulhasan et al. [54] tested if ACL-hamstring stretch reflex could be reliably and consistently obtained using knee arthrometer (KT-2000). They reported that only 70 out of 182 trials (38.5%) elicited stretch reflex, hence the response rate of the anterior cruciate ligament-hamstring reflex is too low for it to be reliably used in a clinical setting. Stretch reflex response rates vary between clinical and intraoperative settings and thus that would suggest that in a more practical environment the response would be less the 40%, which means it is not reliable enough to be used in a clinical setting.

4. Conclusions

For any clinician, the knowledge of anatomy and physiology plays a fundamental role in both the assessment and treatment of a variety of knee injuries. The role of each structure surrounding the knee is vital in providing joint stability. Ligaments, muscles, and joint proprioception together support exercisers during locomotion. The implementation of such knowledge should be a priority when dealing with any knee injury/problem.

Acknowledgments: Jawad F. Abulhasan is funded by a scholarship obtained from the Cultural office at Kuwait Embassy in London. No other financial assistance was received for this project.

Author Contributions: Jawad F. Abulhasan wrote the manuscript and responded to all of the feedback and comments from the co-author. Michael J. Grey supervised the work and provided feedback and comments on every draft of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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