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Chapter

Tibial Femoral Tunnel for Isokinetic Graft Placement Based on a Tensegrity Model of a Knee

Wangdo Kim

Abstract

We characterize the concept of a "knee axis" and further the concept of "invariant." It is now generally recognized that one of the features of the tensegrity (*prestressable to the same configuration*) allows the knee tensegrity system to be in producing the knee instantaneous axis (KIA). We found that the line of the ground reaction force (GRF) vector is very close to the KIA. It aligns the knee joint with the GRF such that the reaction forces are torqueless. The reaction to the GRF will then be carried by the whole structures on the knee tensegrity instead. The use of knee tensegrity model introduces the new useful dimensions of sensitivity in foot loading to the knee axis alignment. We demonstrated a method to determine ideal placement of the tibial tunnel with respect to the KIA. Such placement in vivo has the potential to reliably produce an isokinetic graft without risk of impingement.

Keywords: knee tensegrity system, knee instantaneous axis, the haptic perceptual system, knee alignment

1. Introduction

The perceptual psychologist James J. Gibson regarded the senses as aggressively seeking mechanisms rather than mere passive receivers [1]. The active movement involves the concomitant operation of anatomical components, in which foot touches the ground and rotation of the joints are combined, together with voluntary contractions of the muscles. The total flux of stimulation involved in the so-called active movement is enormously complex, but lawful modes of combination occur. Presumably, the modes of combination of these inputs specify the difference between touching (active) and being touched (passive) [2].

To identify the haptic system's medium, Turvey focused on connective tissue and the conjunction of muscular, connective tissue net, and skeletal as the body's proper characterization [3]. Myers has also posed the medium as a body-wide responsive physiological network—the myofascial meridian [4]. Taking on "geometry" first, cell biologist Donald Ingber placed one final piece of the puzzle: to view the body's architecture in the light of "tensegrity" geometry [5]. "Tensegrity" was coined from the phrase "tension integrity" by the designer R. Buckminster Fuller (working from original structures developed by artist Kenneth Snelson) [6].

The principle of tensegrity describes precisely the relationship between the connective tissues, the muscles, and the skeleton. Weight applied to shank/thigh bones would cause it to slide off its knee joint if it were not for the tensional balances that hold it in place and control its pivoting [7]. The invariant feature of tensegrity structures encompasses those that stabilize themselves through a phenomenon known as prestressing. Architects call this type of prestressed structural network, composed of opposing tension and compression elements that self-stabilizes its shape through the establishment of a mechanical force balance, a tensegrity structure. Biotensegrity is a term introduced by Dr. Stephen Levin and denotes the application of tensegrity's principles to biological structures [8].

Tensional forces naturally transmit themselves over the shortest distance between two points, so the elastic members of tensegrity structures are precisely positioned to best withstand applied stress. For this reason, tensegrity structures offer a maximum amount of strength for any given amount of material [4]. The invariant feature of a knee tensegrity system (specified by a given set of *external forces such as the ground reaction force* (*GRF*)) is a stable equilibrium if the structure returns to the originally given configuration after the application of arbitrarily small perturbations with respect to the KIA anywhere within the configuration [5] (**Figure 1**).

Consequently, estimating of the knee axis is one of the key topics for the "2010 ASME Grand Challenge Competition to Predict in Vivo Knee Loads" [11]. Knee functional axis information is referred to the knee instantaneous axis (KIA)

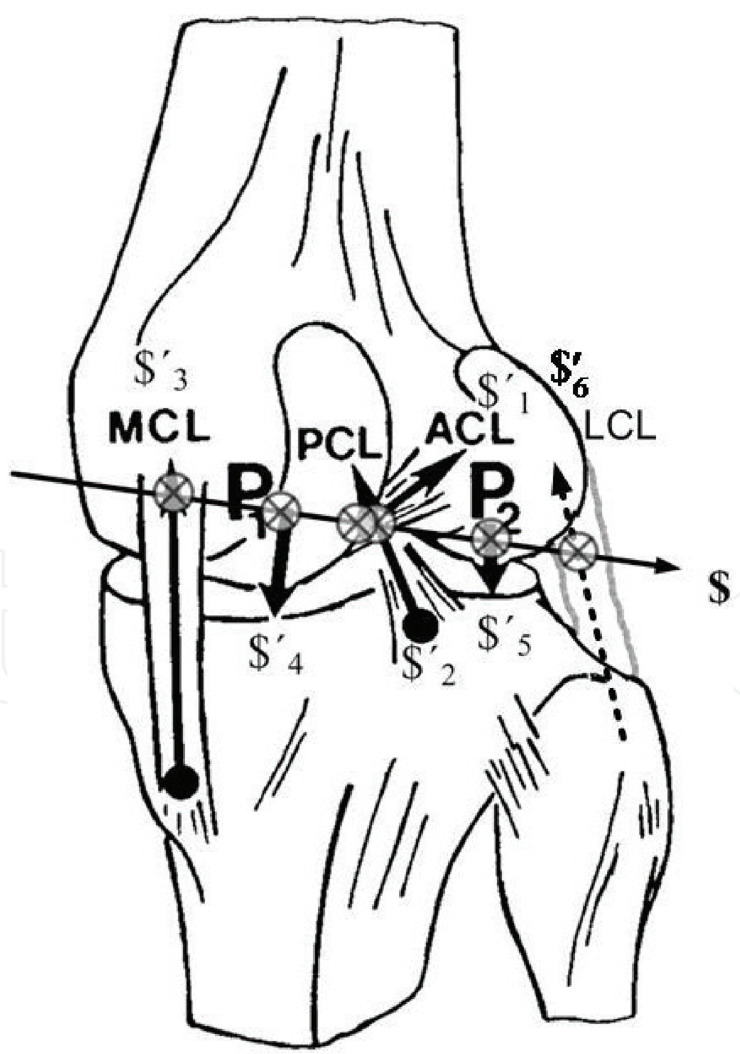

Figure 1.
The tensegrity structure of surrounding forces applied to the knee joint: a native system of the knee where six constraints $´ are collectively reciprocal to the KIA $ indicated by ⊗ that the virtual coefficient should vanish is necessary, and sufficient conditions [9, 10], or the pair ($´ and $) are in involution. The tensegrity's structure is characterized by the contact normal elements $´$_4$ and $´$_5$, while all the other elements are, continuous tension elements, showing specific configuration having torqueless connections.

[12–14]. In that case, the intersegmental force such as ligaments and contact forces are in pure tension/compression and are surrounding the KIA in such a way that those forces result in no (virtual) works [9, 10].

The objective of this study is to show how the knee tensegrity system manages the balance between tension and compression during locomotion by utilizing a unique combination of the KIA and GRF stimuli.

2. Materials and methods

The intra-articular structures of the tensegrity system of the knee include the muscles, the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), and articular contact in the medial (P_1) and lateral (P_2) compartments (**Figure 1**) [15]. We have shown that six constraints are members of the "joint reaction subspace (JRS)" and are spatially oriented in such ways that by imposing an internal tension or "prestress" to reduce the play in the system, this ensures immediate mechanical responsiveness (i.e., that movement of one element is felt by all others) and reduces impact fatigue at the joint.

3. Results and discussion

We have measured the KIA through readily accessible benchmark data [11]. Also, we have measured the GRF on how the progression of the entire body over the limb uses the so-called rockers on foot. The issues of relating the reciprocal connection of the body framework to the movements of cutaneous kinesthesis [9, 10, 15, 16] (zoomed up the pan in **Figure 2**) enunciate that the body's haptic perceptual system registers the covariance of the KIA and GRF. The upward pressure on the surface of support on the ventral side of the foot provides, for every terrestrial animal, a continuous background of stimulation. It is covariant with the continuous input of the appropriate receptors of the articular motion in the knee joint already mentioned. Together they provide what the ordinary person calls the "sense of support."

A unique combination of invariants, such as the KIA and GRF, a *compound* invariant, is just another invariant. It is a unit, and the components do not have to be combined or associated. Only if percepts were combinations of sensations would they have to be associated. Otherwise, we can postulate that when the KIA and GRF are completely covariant when they *always* go together, they constitute a single "stimulus." If the knee tensegrity system is capable of extracting invariants from changing haptic stimuli, there is no reason why it should not extract invariants that seem to us highly complex. Therefore, the reaction torque caused by the foot-ground at the knee will be taken on partially by muscles surrounding the joint.

Perception is not based on the structure of force as it falls upon the plantar side of the foot, the erroneous theory of the passive, sense-datum theory, but on continuous modifications brought about by foot movement which cooperates with body posture to reveal its invariants—a surface of support. The pattern of a compound invariant may indicate the neural loops of an active perceptual system that includes the adjustments of the perceptual organs, our locomotor apparatus. We may suppose that the brain governs the orienting of the organs of perception so that the whole locomotor system of afferent/efferent loops resonates to the patterns of compound invariants [17]. Locomotion is controlled not by the brain, but

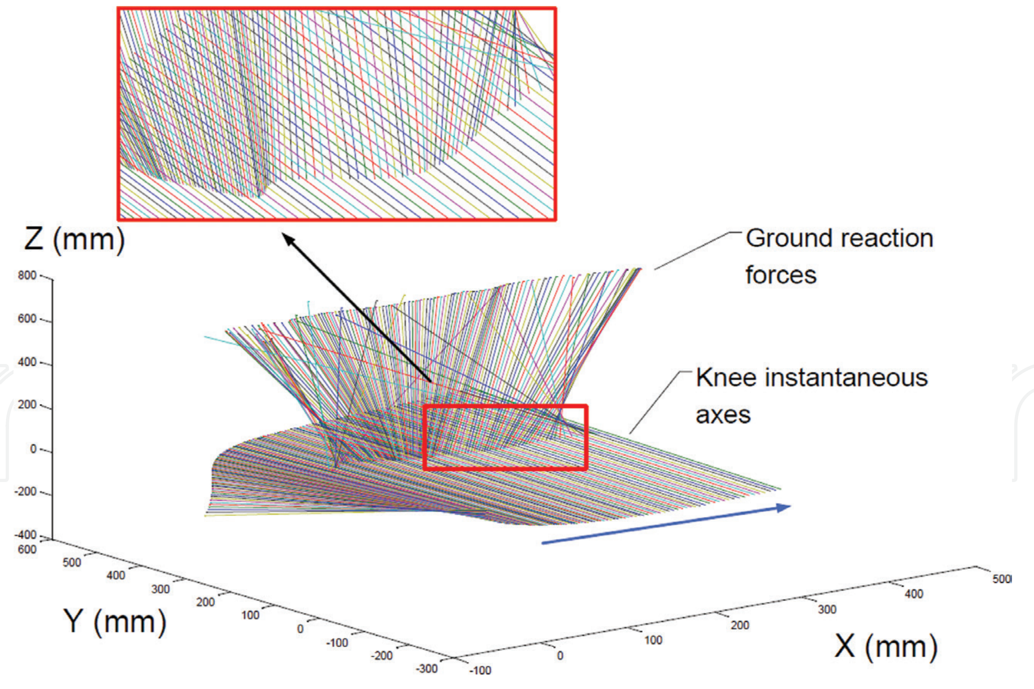

Figure 2.
A unique combination of the KIA and GRF invariant. When deformed by the shank to the ground via GRF, the strain is distributed over the whole structure, not localized in the area being deformed, i.e., the joint itself. A reaction torque is zero on the knee joint if the GRF line of action intersects the joint axis, or the configuration can exert a large force on the ground without overloading the knee joint. A considerable ground reaction force can be exerted on a foot when the vector nearly coincides with a reciprocal screw of joints. It is indicative of the "sense of support" being manifested based on the close correspondence of the vector of the ground reaction force at COP, and the IAK with fluctuations at the spatial scale of a millimeter (GRF-KIA coupling).

by information. We showed that the GRF might reciprocally be used to control locomotion.

We should choose surgical procedures that not only reconstruct the anatomy but also restore the articular kinesthesis, that is, the pickup of own movement [18–21]. In such an application, avoiding roof impingement during reconstruction of a torn ACL might find benefit in choosing a tunnel placement that can come near to a tensegrity model of a knee.

We found that the line of the ground reaction force (GRF) vector is very close to the KIA. It aligns the knee joint with the GRF such that the reaction forces are torqueless. The reaction to the GRF will then be carried by the whole structures on the knee tensegrity instead.

Conflicts of interest

The author declares no conflicts of interest.

Abbreviations

COP	center of pressure
GRF	ground reaction force
KIA	knee instantaneous axis

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