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The Dynamic Rotating Functional Knee Orthosis Concept

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INTRODUCTION

The human knee is a masterpiece of engineering. As the largest and most complex joint, it is one of the most vulnerable for injury. Any disruption in the structures, in or around the knee, has been shown to create a functional loss or change in the mechanics of the knee joint. Motion of the knee occurs simultaneously in three planes: frontal (coronal or longitudinal), sagittal, and transverse (horizontal). However, the motion in the sagittal plane is so significant that it accounts for most of the knee motion.

Knee orthoses have, historically, been primarily designed to impart rigidity to the knee and to restrict motion in order to provide stability. Many orthoses are fabricated either from cast impressions, tracings of the leg, or both, implying that an intimate fit with the extremity and functional stability are obtained by the custom fabrication. The external hinge joints used today follow kinematic pathways, which are considered simpler than that of the anatomic knee. Orthotic joints may be grouped into three categories as follows. First, the fixed axis type that allows for a single axis of motion. Second, the polycentric systems provide for the natural posterior motion of the femur relative to the tibia producing equal motions on each side of the joint. Third are the "anatomical" systems that attempt to duplicate the asymmetrical knee motion during flexion.[10, 17]

These joints are combined with various designs of cuff configurations to produce an orthosis that will attempt to generate the relative motion that resembles that of the normal knee. However, the mismatch between the orthotic and anatomic knee joint motions still exists, causing restriction of normal range of motion, distal migration of the orthosis, and condylar separation. Even with the "Anatomical" systems, placement and maintenance of proper position are critical to function.

This paper will review the scientific basis for the development of a completely new concept in functional orthotics which allows dynamic stabilization. It will also review the kinematics of the knee during the gait cycle and outline the role of the proprioceptive reflex arc in causing disabling subluxation episodes in unstable knees.

Anatomy

In the normal gait cycle, the foot/ankle complex is supinated at heel strike and the knee is extended with the tibia in an externally rotated position.[2, 12] The collateral

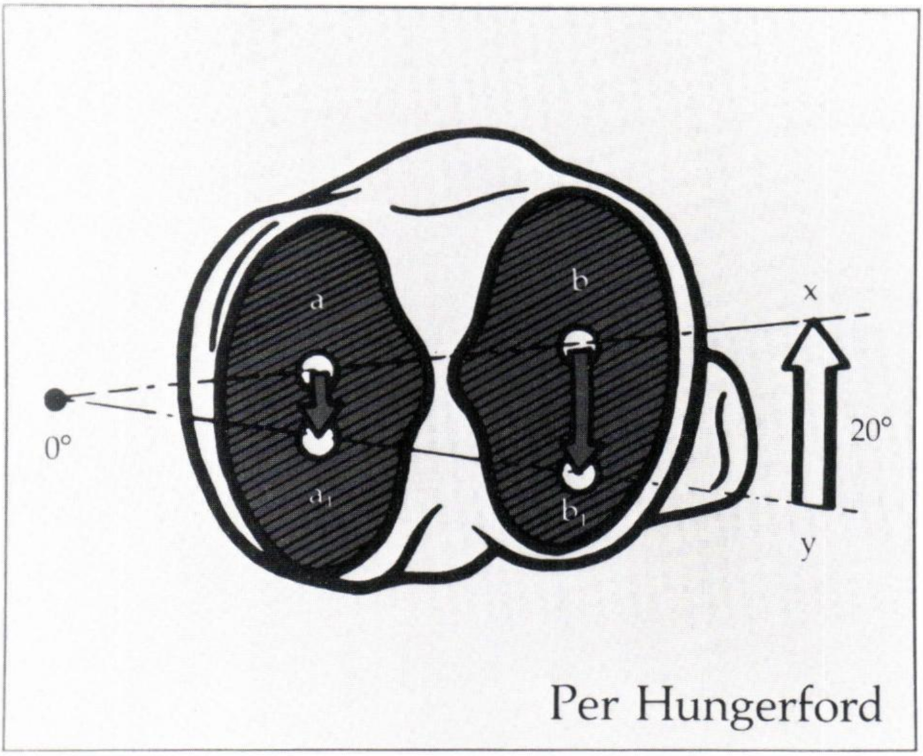

Figure 1. Automatic rotation tibial-femoral points of contact in extension (a, b) and flexion (a_1, b_1).

ligaments tighten and inhibit excessive rotation by becoming crossed in space. The foot is quickly lowered to a flat position by an eccentric contracture of the Tibialis Anterior muscle and the knee progressively flexes and undergoes internal rotation. The collateral ligaments become more vertical and so are lax, while the cruciate ligaments become coiled around each other and begin to come under strong tension. At midstance phase, maximum pronation of the foot/ankle complex is achieved and maximum internal rotation of the knee is produced. The beginning of toe off starts with the progressive supination of the foot/ankle complex and the accompanying external rotation of the tibia to push off phase.

While the amount of tibial rotation can vary between individuals, tibial rotation must always be present for the knee to function in an anatomic way. The anatomic structures of the femoral condyles, the tibial plateau, and the menisci have been well documented by Muller.[12] The lateral femoral condyle undergoes two to three times the amount of relative anterior/posterior excursion as the medial femoral condyle.[17] In fact, for the internal and external rotation aspects of the normal gait cycle of the knee to occur, the axis of rotation is actually somewhat medial to the medial tibial plateau for this excursion process (Figure 1).[7, 8, 16] In the last 20° to 30° of extension, the "screw home mechanism" occurs with progressive internal rotation of the femur, leading to external rotation of the tibia. Therefore, for the tibia to approach its normal degree of rotation in extension, any external orthosis applied must allow for this anatomic rotation to occur. To accommodate this, the axis of rotation of the orthosis or of the tibial component of the orthosis must be medial to the medial tibial plateau at the normal axis of rotation of the knee. Only in this location can the lateral plateau move in greater anterior/posterior distance than the medial plateau.

Discussion

It now seems evident that any form of external support, no matter how rigid, will generally be doomed to failure if judged by static testing. Two recent studies[1, 4] in the *American Journal of Sports Medicine* draw two seemingly conflicting conclusions. First, no external orthosis can either replace or approach the static resistance provided by the normal anterior cruciate ligament and, secondly, the majority of patients with symptomatic anterior instability of the knee are improved by wearing any of the various orthoses. Paulos[14] states that in his study he demonstrated anterolateral tibial subluxation in every patient in every functional knee orthosis examined by the Losee test. Nonetheless, "Our subjective results show that most patients like to use the braces despite the fact that we could not mechanically show they were working." Because of the external nature of the orthoses and the large amount of soft tissues in the thigh, all orthoses will allow significant passive movement when tested in a static manner. The fact that body type has been shown to influence orthosis performance further supports this conclusion.

There are several shortcomings in the various orthoses on the market today. The most restrictive of these types are those systems with rigid tibial and femoral components linked by rigid double upright hinges. The benchmark, which most functional orthoses have been judged against, is the Lenox Hill Brace.[13] While the orthosis is totally rigid and totally custom made, it has no rotational mechanism in it, yet it is called a derotational brace. This design is rigidly fixed by double uprights to the thigh and calf. There is either no rotation allowed in the extremity, or the normal rotation takes place between the orthosis and skin interface, or the skin envelope around the leg. While the rigidity imparted by this type of orthosis would certainly increase the resistance to subluxation of the tibia and therefore provide a resistance, at the same time it resists the normal motions that need to occur during functional activity, i.e., flexion and external rotation.[9] On the other hand, the more flexible orthoses with their inherent lack of rigidity do not seem to perform as well subjectively, because less rigidity is imparted to the knee structure.

In prior studies, several key factors have been brought out about knee orthoses:

a. they improve static stiffness at low loads;[1]
b. at high static testing, all orthoses allow tibial subluxation;[4]
c. most episodes of buckling at the knee occur during low load, low force situations;[4]
d. significant forces are required to sublux a loaded knee;[6, 11]
e. post injury rehabilitation does not necessarily correlate with subjective improvement of performance and symptoms when the patient is put in an orthosis.[15]

The term "low load" ligament function is defined as when the ligaments keep the correct apposition of the articular surfaces during muscle-generated function, providing for proper joint lubrication and normal contact forces. The term "high load" ligament function is defined as the ligaments providing stability in a traumatic situation where the external load occurs too rapidly for the muscles to equilibrate.

Rationale

With the above information, it is clear that other factors must be present that are responsible for the subjective improvement gained through functional support of the knee. It is our hypothesis that the major factor involved in successful orthotic care is the establishment and maintenance of the proper tibia-femur relationship prior to loading of the knee in the low load situation. All joints have a proprioceptive reflex arc that gives unconscious protection against joint injury if a load is applied in any position other than a conjugated one.[5, 12] In knee joints, stretching an interarticular ligament can elicit firing from proprioceptors situated only in the ligament.[3] Therefore, whenever an unstable knee is loaded in a subluxed position, there is an immediate reflex arc that produces a muscle inhibition and subsequent "giving way" sensation. No matter how strong the muscles are, the reflex inhibition will elicit a "giving way" episode if the joint is not conjugate.[3] However, once a conjugate joint is loaded, extreme forces are required for subluxation.[6, 11] For this reason, rehabilitation is most important in the unstable knee. It is our premise that all orthoses function by helping to resist the subluxation in the low force, unloaded position, allowing a proper tibia-femur relationship to exist prior to heavy loading of the knee. This can easily explain the benefits gained from functional orthotics even in the unrehabilitated knee.

While the more rigid orthoses provide for greater rigidity, they have no ability to allow for rotation; therefore, the capability to prevent subluxation is less. During the last 20°-30° of knee extension, the tibia is undergoing a progressive external rotation as the "screw-home" mechanism takes place. Any orthosis which does not allow rotation to occur can prevent or minimize rotational excursion in terminal extension. Therefore, if an orthosis minimizes the external rotation of the tibia in terminal extension, by definition, it would be minimizing the distance of travel required to sublux the knee anterolaterally. Based on this fact, we, in conjunction with 3D Orthopedic, have designed an orthosis that dynamically produces an external rotation force that is greater as the knee extends and allows for the tibia to be held in a more reduced position during terminal extension. This allows for a greater capability in preventing subluxation prior to loading. The orthosis also provides an adjustable rigid stop to block excessive internal rotation beyond a normal degree by its rigid link to the medial upright (Figure 2).

Summary

We feel that all functional orthoses work by eliminating or reducing knee subluxation at low loads, thereby preventing the activation of the proprioceptive arc reflex which causes disabling buckling of the knee. The term "low load" implies either passive or active forces acting upon the tibia prior to taking full body weight on the extremity, during either routine walking or high performance activity. If the proper tibia-femur relationship is maintained, the buckling phenomenon will be eliminated. This concept can adequately explain the following observations made by prior investigators: a) The orthosis is seen to increase relative knee stability, even though maximal laxity remains unchanged; b) Stability is greatly increased by loading a knee; and c) Symptoms of instability seem to be improved by increasing resistance to low forces of displacement. This implies that episodes of subluxation occur during low force, low load situations, giving rise to the clinical "giving way" experienced when the knee is then loaded.

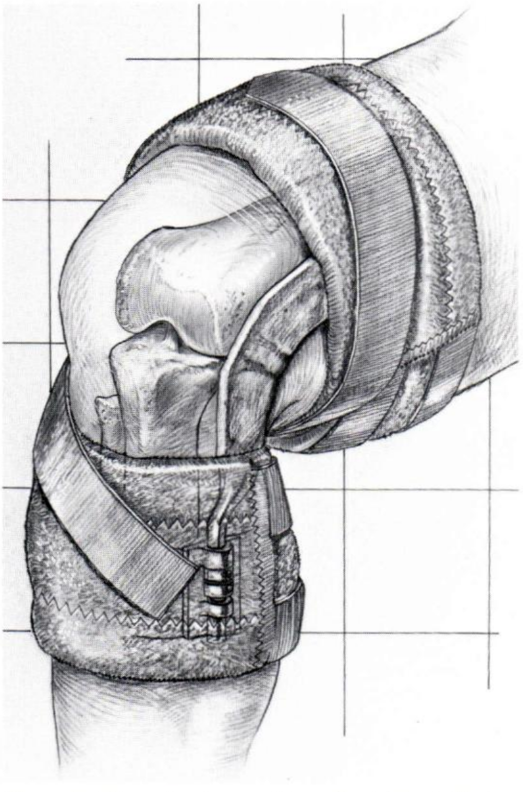

Figure 2. The orthosis provides adjustable rigid stop to block excessive internal rotation beyond a normal degree by its rigid link to the medial upright.

The 3D Dynamic Functional Knee Brace clearly accomplishes the goal of maintaining the conjugated tibia-femur relationship. The medial post and hinge help the knee track with normal rotation during gait by the true dynamic rotation strap action. Thus, normal knee kinematics are recapitulated actively by this orthosis.

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