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Biomechanical Considerations in the Orthotic Management of the Knee

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The challenges facing the contemporary orthotist are akin to the interminable task of Sisyphus, the Greek mythic figure who was condemned to pushing a huge rock up an endless hill. Unlike Sisyphus, however, the orthotist has made and continues to make significant strides in the rational design and fabrication of prostheses and orthotic devices. Over the past decade major contributions to solving the anatomical and functional problems associated with joint replacement prostheses and orthoses have directly resulted from the growing interaction between orthopaedic surgery and biomechanics. The result of this increased interaction has been improved diagnosis and treatment of musculoskeletal disorders with prostheses and orthotic devices. The knee is certainly one of the joints that has greatly benefited from these biomechanical developments.

Biomechanics enables the scientist to accurately describe and quantify surface joint motion of the knee and to analyze the complex forces imposed on the knee. Biomechanics also brings the motion of and the forces acting on the knee into sharp focus by analyzing the mechanical properties of the static and dynamic structures surrounding the knee: muscles, bones, ligaments, cartilage, and tendons. The biomechanical analysis of motion and force in the knee joint can be widely and successfully applied in orthotic management of the knee.

The human knee is the largest and perhaps the most complex joint in the body. It is a two-joint structure composed of the tibiofemoral joint and the patellofemoral joint. Both joints sustain high forces and, located between the body's two longest lever arms, are particularly susceptible to injury. The knee transmits loads, participates in motion, aids in conservation of momentum, and provides a force couple for activities involving the leg.

Although motion in the knee occurs simultaneously in three planes, the motion in one plane is so great that it accounts for most knee motion. Similarly, muscle forces on the knee are produced by several muscles, but a single muscle group (according to the activity) produces a force so large that it accounts for most of the muscle force acting on the knee. Thus, biomechanical analysis can be basically limited to motion in one plane and to the force produced by a single muscle group, and yet can still give an understanding of knee motion and an estimation of the magnitude of the main forces acting on the knee.

To analyze motion in any joint, one must use kinematics, the branch of mechanics that deals with motion of a body without reference to force or mass. To analyze the forces imposed on a joint one must use both kinematic and kinetic data. Kinetics is the branch of mechanics which analyzes the motion of a body under the influence of given forces.

Kinematics

Kinematic data define the range of motion and describe the surface joint motion in three planes: frontal (coronal or longitudinal), sagittal, and transverse (horizontal).

The range of motion can be measured in any joint and in any plane. Gross measurements can be made by goniometry, but more specific measurements must be made with more precise methods such as electrogoniometry, roentgenography, or photographic techniques using skeletal pins.[5,6,7]

The range of knee joint motion needed for performing various physical activities can be determined from kinematic analysis. A full range of knee motion is needed for performing the more vigorous activities of daily life in a normal manner. Moreover, any restriction of knee motion will be compensated for by increased motion in other joints.

The values obtained in several studies indicate that full extension and at least 117 degrees of flexion are necessary

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for carrying out the activities of daily life in a normal manner (Table 1).[2,5,8]

Surface Joint Motion

Surface joint motion, the motion between the articulating surfaces of a joint, can also be described for any joint in the sagittal and frontal planes, but not the transverse plane. The method used is called the instant center technique. This technique allows a description of the relative uniplanar motion of two adjacent segments of a body and the direction of displacement of the contact points between these segments. The instant center for motion of a planar joint can be obtained by the method of Reuleaux (1876).[9]

Clinically, a pathway of the instant center for a joint can be plotted by taking successive roentgenograms of the joint in different positions (usually ten degrees apart) throughout the range of motion in one plane, and applying the Reuleaux method for locating the instant center for each interval of motion. After the instant center pathway has been determined, the surface joint motion can be described. In a normal knee, the instant center pathway for the tibiofemoral joint is semicircular.

Especially pertinent to orthotic management is data concerning knees with internal derangements. If the knee is extended and flexed about a displaced instant center, the tibiofemoral joint surfaces do not slide tangentially throughout the range of motion, but become either distracted or compressed. Such a knee is analogous to trying to close a door with a bent hinge. If the knee is continually forced to move about a displaced instant center, it will gradually adjust to this situation by either stretching the ligaments and supporting structures of the joint or by exerting abnormally high pressure on the articular surfaces.

Such internal derangements of the tibiofemoral joint may interfere with the so-called screw-home mechanism, which is a combined motion of knee extension and external rotation of the tibia. The tibiofemoral joint is not a simple hinge joint, but has a spiral, or helicoid, motion. The spiral motion of the tibia about the femur during flexion and extension results from the anatomical configuration of the medial femoral condyle; in a normal knee this condyle is approximately 1.7cm longer than the lateral femoral condyle. As the tibia slides on the femur from the fully flexed to the fully extended position, it descends and then ascends the curves of the medial femoral condyle and simultaneously rotates externally. This motion is reversed as the tibia moves back into the fully flexed position. The screw-home mechanism gives more stability to the knee in any position than would be possible if the tibiofemoral joint were a simple hinge joint.

The Helfet test, a simple clinical test, is used to determine if external rotation of the tibia occurs during knee extension, thus showing whether the screw-home mechanism is intact.[3]

In a deranged knee it may happen that no external rotation of the tibia occurs during extension. Because of the altered surface motion, the tibiofemoral joint will be abnormally compressed if the knee is forced into extension, and the joint surfaces may be damaged.

Table I

Range of Tibiofemoral Joint Motion in the Sagittal Plane During Common Activities

Activity	Range of Motion from Knee Extention to Knee Flexion (degrees)
Walking	0–67*
Climbing Stairs	0–83**
Descending stairs	0–90
Sitting down	0–93
Tying a shoe	0–106
Lifting an object	0–117

*Data from Kettelkamp et. al., 1970. Mean for 22 subjects. A slight difference was found between right and left knees (mean for right knee 68.1 degrees; mean for left knee 66.7 degrees).

**From Laubenthal, et. al., 1972. Mean for 30 subjects.

Kinetics

Kinetic data, based on static and dynamic analysis, are used to analyze the forces acting on a joint. The medical scientist can use kinetic analysis to determine the size of the forces imposed on the knee by muscles, body weight, connective tissues, or external loads in either static or dynamic situations. In particular regard to orthotic management, however, situations and movements which produce excessively high forces can be identified.

In static analysis, the three main coplanar forces acting on a body in equilibrium are identified as: (1) the ground reaction force (equal to body weight), (2) the tensile force exerted by the quadriceps muscle through the patellar tendon, and (3) the joint reaction force acting on the tibial plateau. Since most of our activities are dynamic, however, an analysis of the forces acting on the knee during motion—dynamic analysis—must be applied to given situations. In addition to the three coplanar forces of static analysis, the medical scientist must also take into account the acceleration of the body part (the amount of torque needed to accelerate a body, for which anthropometric

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data-tables are used).[1] An orthotist might use dynamic analysis, for example, to calculate the joint reaction, muscle, or ligament forces on the tibiofemoral joint at a particular instant in time during walking, or at a particular instant in time (with a stroboscopic film) while kicking a football.

Other biomechanical considerations in the orthotic management of the knee involve the two important functions of the patella: (1) it aids knee extension by lengthening the lever arm on the quadriceps, and (2) it allows a better distribution of stresses on the femur by increasing the area of contact between the patellar tendon and the femur. In a patellectomized knee, for example, the quadriceps muscle, now with a shorter lever arm, must produce even more force than normal to achieve the required torque about the knee during the last 45 degrees of extension. Full, active extension of a patellectomized knee may require as much as 30 percent more quadriceps force than normally required.[4]

During most dynamic activities, the greater the knee flexion, the higher all the muscle forces acting on the patellofemoral joint. Forces increase proportionately with knee flexion, for example, from walking to stair climbing to knee bends. Patients with patellofemoral joint derangements experience increased pain when performing activities requiring knee flexion, and orthotic management could be greatly aided by knowledge of such predictive biomechanical factors as knee flexion, and the muscle and joint reaction forces for specific situations.

Biomechanical analysis can yield invaluable, practical data for the orthotic management of the knee. A continuing, close interaction among orthopaedic surgeons, bioengineers, and orthotists will insure the applied efficacy of such data.

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The Role of Orthoses in the Care of Knee Ligament Injuries

by Kenneth E. DeHaven, M.D.*

The role of braces in the management of knee ligament injuries, particularly in high risk athletics, continues to receive a great deal of attention. There are a multitude of braces currently being manufactured and marketed with various claims relating to the effectiveness, comfort, durability, and cost.

Two key questions remain for most clinicians: (1) Should knee braces be used at all?, and (2) If so, what type of brace should be used and under what circumstances? At present there is a paucity of scientific data available to answer either of these questions with certainty, but there are encouraging signs that this essential information will be forthcoming from current and future research. Until an adequate scientific basis has been established it is necessary to develop a philosophy about bracing in athletics that is consistent with the data that is available and our clinical observations.

Should braces be used at all?

There is frequently an ego problem for both the athlete (who views a brace as a sign of weakness) and the physician (concern that a brace reflects less than optimal results) who delight in the statement "Doc, I don't need that brace—I can run and cut without it." Definitive treatment, whether rehabilitation or surgery followed by rehabilitation, must provide the functional stability, and it is rare in my experience that an unstable knee is made stable simply by applying a brace. However, no matter how good it might feel to the athlete, a knee that has previously sustained major ligament injury is not normal, and in fact has suffered ligament disruption at a time when it was normal. The role of bracing, therefore, is not to provide stability but to help prevent reinjury by keeping the knee from going into extreme positions when subjected to sudden stress. When presented in this light, the concept of protective bracing after major ligament injury to the knee is more reasonable and more acceptable to both the athlete and the physician.

What type of brace should be used and under what circumstances?

While not definitively established, it appears that the beneficial effects of knee orthoses are related not only to their mechanical strength but also to providing increased proprioceptive input from the knee area (which can ex-