Knee Bracing

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Abstract

The authors present an overview of the design and functional features of knee braces and their relationship to knee biomechanics. Four types of knee braces—prophylactic, rehabilitative, functional, and patellofemoral—have been developed to cover the wide variety of indications in patients who have suffered knee injuries or hope to prevent them. Important considerations when choosing specific brace types are discussed, and summaries of relevant research are presented. Clinical criteria for brace selection are offered to help physicians and sports medicine professionals in choosing the right brace for each patient.

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The usefulness of bracing for the treatment of knee instabilities has long been a topic of controversy. In spite of patient support for knee braces, the majority of clinical and biomechanical studies have demonstrated little or no benefit from these devices under physiologic loading conditions. Despite this controversy, clinicians still are required to make informed decisions pertaining to the proper role of knee bracing for their patients. These decisions demand not only an ability to assess the patient's stabilization requirements but also a working knowledge of brace types, functional design constraints, and effectiveness.

The purpose of this article is to summarize the information that will be clinically useful in determining the proper role of bracing in knee injuries. The biomechanics of bracing will be discussed, as well as the functional characteristics and efficacy of the four types of knee braces and recommendations for their use.

Basic Biomechanics of Bracing

Knee Mechanics and Stability

The knee and its associated musculature can be viewed as a semiconstrained motion unit with feedback control that responds to internal and external forces to create stable, complex, three-dimensional joint motions in both the loaded and the unloaded state. During dynamic activity, powerful muscle groups (primarily the quadriceps and hamstrings) exert moments and forces and work synergistically with soft-tissue restraints (the ligaments, capsule, and menisci) and the surface geometry of the bones to position the knee for optimal loading and energy conservation.

During most of the activities of normal living, the major motions of the knee are flexion and extension. However, concomitant or coupled rotations and translations occur in the transverse plane (internal and external rotation, joint compression and distraction), the frontal plane (varus and valgus rotation, medial and lateral shear), and the sagittal plane (anterior and posterior shear), especially near or at the extremes of motion. These couplings are the result of mechanical limits placed on skeletal positioning by associated anatomic structures. The summation of these effects defines the envelope of safe motion, or "inherent stability," of the knee.

Major factors that directly affect the inherent stability of the knee include (1) skeletal structure, (2) joint-contact forces, (3) the integrity of intra-articular and extra-articular soft-tissue restraints, and (4) neuromuscular facilitation. As a result of injury, disease, or the aging process, the influence of any of these factors may become significantly diminished. Pathologic laxity with or without functional instability may result as the range of knee motion is increased beyond the envelope of safe motion. The presence of pathologic laxity places the remaining

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undamaged restraining factors at greater risk for traumatic or chronic fatigue injury.

Brace Function and Design

The major objectives of current knee-brace designs are to resist abnormal joint motions, to augment the inherent mechanical stability of a normal knee (prophylactic and functional bracing), and to assist in restoration of normal mechanical stability in an injured or rehabilitating knee (postoperative bracing). Each type of knee brace is designed to perform a specific function. Three design features are critical to selection of the appropriate brace: the mechanical properties of the brace, the brace fit, and the hinge design.

Mechanical Properties

Braces exert control on skeletal positioning by applying mechanical leverage by means of uprights, hinges, and calf and thigh cuffs and straps. Factors that increase the amount of leverage produced by knee braces include the following: (1) the length of the uprights (longer uprights reduce the moment arm or force applied directly to the knee joints); (2) the number of fixation points (four points are superior to three [Fig. 1]); (3) fit (contour fit is best); and (4) material properties (stiffer, lighter-weight, and durable materials are preferred). Whenever possible, the leverage application point should provide purchase on directly subcutaneous bone, such as the tibial tuberosity or the medial and lateral condyles.

Brace Fit

Braces generally come in two forms, off-the-shelf braces (typically in four or five preset sizes) and custom braces, which are individually fitted to the patient's anatomy. Off-the-shelf braces are usually less expensive than custom braces and should be used when the limb contour is still changing, such as during early rehabilitation. Custom braces are considered a long-term investment and should be used only after limb dimension has stabilized.

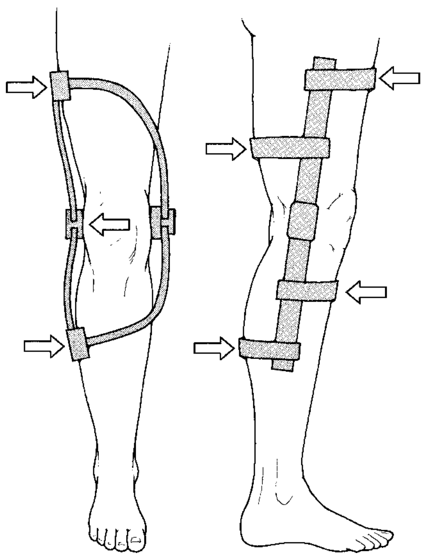

Fig. 1 Brace designs incorporating three-point **(left)** and four-point **(right)** force application systems. Arrows denote locations of force application.

Hinge Design

The hinge is the mechanical component of the brace that allows the knee to flex and extend and through which leverage is applied. Walker et al[1] demonstrated that, because of the soft-tissue covering of the leg, single-center hinges are as effective as "anatomic" or polycentric hinges, which are designed to closely track knee motion. Important features of hinge design include durability, strength, range of motion control, and smooth action.

Mechanics of the Knee-Brace Composite

There are several factors related to the knee-brace interface that significantly influence brace competence. First, brace control of skeletal motion is always mediated through soft-tissue coverings. This limits brace effectiveness for the control of internal and external rotation and anterior and posterior displacement of the tibia on the femur.

Second, braces that are secured against subcutaneous skeletal prominences can exert more leverage, and thus produce better motion control, than less conforming braces. Braces with well-designed condylar pads are able to efficiently resist varus and valgus motion.

Third, well-designed braces function by addressing coupled motion as well as major-axis knee motions. Since most of the motion coupling is related to terminal or accentuated positions of flexion or extension, resistance to abnormal coupled motions can be achieved by blocking terminal extension in anterior cruciate ligament (ACL) injury or flexion in posterior cruciate ligament injury. The blocking of extremes also places the knee in a better position to take advantage of muscle-mediated joint compression, a recognized stabilizing maneuver. For example, limiting extension and valgus motions results in resistance to external rotation. Although this concept is not completely understood, we suspect that many of the resistive effects of current brace designs are related to coupled motion control. However, no study to date has evaluated this hypothesis.

Brace Types

In a 1985 report,[2] the American Academy of Orthopedic Surgeons (AAOS) Committee on Sports Medicine defined three categories of braces: prophylactic, rehabilitative, and functional. For completeness, we will also discuss a fourth category, patellofemoral (PTF) braces.

Prophylactic Braces

Functional Characteristics

The objective of prophylactic bracing is to prevent or reduce the severity of injury to the healthy soft-tissue restraints of the knee. According to the AAOS report,[2] prophylactic braces should increase resistance to injury without interfering with normal function, increasing risk of injury to other lower-limb structures, or constituting a hazard to other players.

The most commonly used prophylactic brace is the lateral knee guard worn by athletes participating in contact sports (Fig. 2). It is designed to protect the knee from lateral impacts that can result in medial collateral ligament (MCL) and cruciate ligament injuries.

Lateral knee braces usually consist of a unilateral upright with a single or duocentric hinge. They are applied to the lateral calf and thigh with adhesive tape or elastic straps by means of brace paddles. A few designs use bilateral bars and hinges, but these are less popular because of interference if braces are worn on both legs. The more efficient braces incorporate energy-absorbing design features, are made of durable lightweight materials, and stiffen the knee to valgus opening. The energy-absorbing features include adjustable paddles to accommodate limb-contour variations, elastically deformable side bars, and medial support straps.

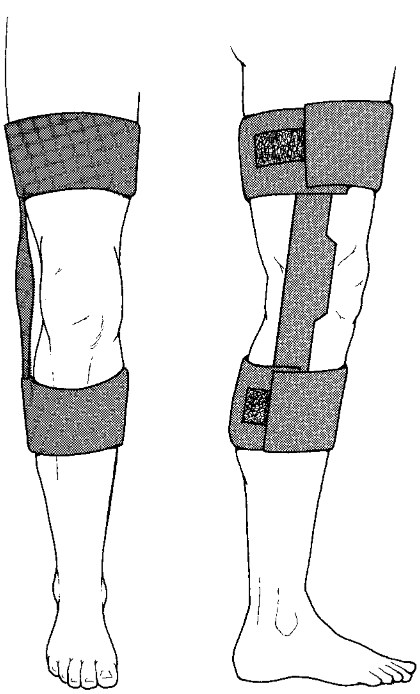

Fig. 2 Lateral prophylactic knee brace.

Efficacy

Numerous biomechanical and clinical research studies have been conducted to determine the effectiveness of prophylactic braces. Biomechanical tests using both human cadavers and mechanical surrogate models have demonstrated differences in protective ability related to brace design for impact resistance, knee position at the time of impact, and impact magnitude and duration profile.[3,4] In tests performed in our laboratory, braces that were relatively stiff and that absorbed, transmitted, and distributed the energy of impact away from the knee performed best.[4] Only one brace of six tested provided even moderate protection for direct low-energy lateral impacts with the foot planted and the knee extended—-a trauma often experienced by the interior line in American football.

A review of clinical research pertaining to prophylactic bracing demonstrates an obvious lack of consensus. Study design flaws related to inaccurate data collection methods, nonstandardized injury diagnoses, and inconsistencies created by yearly variations in coaching techniques and game rules have limited the usefulness of most of the clinical data. For further discussion of this problem, we refer the reader to an excellent article by Requa and Garrick,[5] who critically reviewed the study design and results of six clinical studies on this topic.

An exception to most clinical studies is the well-controlled, prospective, randomized evaluation by Sitler et al,[6] who analyzed the brace type that had proved most effective in a biomechanical study. The authors studied changes in the frequency, severity, and etiology of knee ligament injuries in 705 non-braced and 691 laterally braced West Point cadets who were of similar age, height, weight, and playing experience and who participated in intramural tackle football over a 2-year period. They found that the injury rate for the nonbraced group was significantly higher (3.4 injuries per 1,000 exposures) than for the braced group (1.5 per 1,000 exposures). The number of MCL injuries related to lateral blows and the severity of ACL and MCL injuries were both lower with brace use. There was also a trend toward reduction in the rate and severity of MCL injuries in interior linesmen and defensive players.

Recommendations

Currently there is no consensus pertaining to the need for prophylactic bracing. However, the most recent clinical and biomechanical research studies indicate that braces can be beneficial in reducing the number of MCL injuries due to direct lateral blows to the knee, especially at or near full knee extension. An effective brace should (1) maintain the position of the hinge at the lateral joint line with no inferior migration during play, (2) preserve joint-line clearance during the impact, and (3) possess sufficient length, stiffness, and elastic properties to control the amount of impact energy delivered to the knee. The brace with the longest lever arms, which move the point of contact away from the knee joint to allow soft-tissue absorption of the force, will be most effective in reducing knee ligament forces during impact. The athlete should be educated to understand that, although the brace will increase the stiffness of the knee, common sense is the most effective defense against injury.

Rehabilitative Braces

Functional Characteristics

Rehabilitative, or postoperative, braces are designed primarily to control the knee flexion-extension angle during the initial healing period after either cruciate ligament or meniscal injury or repair or reconstruction procedures. They are used by partial-weight-bearing and non-weight-bearing patients during crutch-assisted ambulation immediately after injury or surgery as a means of reducing pain, avoiding excessive ligament strain, and providing protection if accidental weight application occurs. Rehabilitative bracing is considered superior to full knee immobilization because the allowed motion and loading reduce muscle atrophy, maintain cartilage health, and decrease the chances of knee stiffness.

Postoperative braces consist of (1) adjustable foam liners placed to surround and protect the calf, thigh, and knee; (2) full-length bilateral arms or paddles with hinges to control range of motion, which are placed on the medial and lateral sides of the leg; and (3) six to eight nonelastic straps that interface with the hinge arms, surround the foam liners circumferentially, and hold the components of the brace together (Fig. 3). Some models also include a foot piece to reduce inferior brace migration.

Efficacy

There is little data on the clinical performance of rehabilitative braces. The reasons for the lack of such information may be related to the limited period of use of a rehabilitative brace, which is usually replaced by a functional brace as rehabilitation progresses, or it may be related to the perceived simplistic function of the brace, which leads researchers to exclude it from the rigorous scrutiny of a clinical trial. Nevertheless, these devices appear to be accepted clinically on the basis of their subjective success.

Of the few biomechanical studies pertaining to postoperative bracing, the most definitive work was performed by Cawley et al,[7] who used a mechanical surrogate of the lower limb that was designed to replicate the stiffness and motion response of a normal knee and a ligamentously weakened knee. The effectiveness of eight different rehabilitative braces in controlling knee extension, anterior and posterior tibial translation, and valgus rotation was evaluated. Most of the braces tested significantly reduced both knee translation and rotation during low-load testing, which was designed to mimic partial weight-bearing. Two braces failed to hold knee extension due to hinge failure.

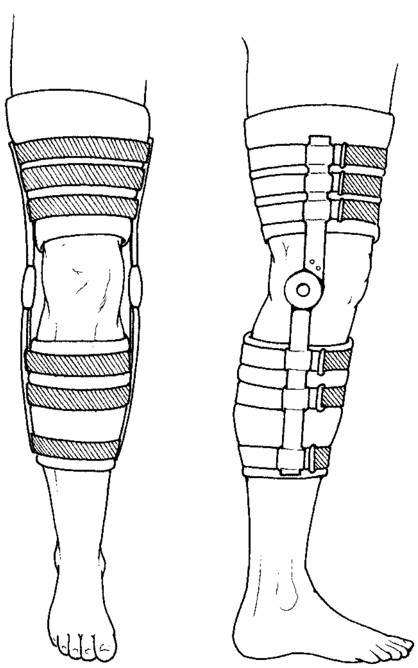

Fig. 3 Rehabilitative (postoperative) knee brace.

On the basis of the results of this analysis, several observations pertaining to effective brace designs were made. The braces that controlled strap and arm position during loading exerted better control of flexion and extension. Varus / valgus control was best with braces that demonstrated joint-line contact and had proper fit. Braces that provided the best anterior translation control distributed the load along the entire length of the thigh and calf through well-integrated bar-and-strap systems.

Recommendations

Rehabilitative braces are currently recommended during the initial healing period immediately after injury or surgery. They are considered superior to total immobilization because they allow limited joint motion and weight-bearing. Since all rehabilitative braces incorporate padding to reduce knee pain, hinge range-of-motion controls must be set tighter to offset leg motion within the brace. Usually, a 20- to 30-degree reduction from the desired range is appropriate.

Desirable design features of rehabilitative braces include (1) an adjustable overall fit to accommodate changes in limb circumference related to edema and atrophy; (2) hinges that fit close to the joint line; (3) range-of-motion control that can be easily adjusted to accommodate rehabilitation therapy; and (4) an integrated locking bar-and-strap system. Since use of the brace is usually short-term (approximately 8 weeks), low-cost off-the-shelf models are recommended. Some manufacturers sensitive to the economics of bracing produce a brace that will convert to a shorter version for intermediate use until a functional brace can be considered.

Functional Braces

Functional Characteristics

Functional braces are designed to control normal motions as well as resist abnormal rotation and translation produced by failure of the soft-tissue restraints of the knee. Most functional braces address abnormal motions associated with ACL deficiency and reconstruction with or without related secondary restraint damage. Although some manufacturers claim that their brace can control internal and external rotation, the deficiencies imposed by the soft-tissue–brace interface make current functional brace designs ineffective for axial rotation control. However, most brace designs provide some limited resistance to abnormal varus and valgus angulation and anterior translation. This control is usually produced as a coupling effect with extension and flexion motion control.

There are currently over 30 models of marketed functional braces in both off-the-shelf and custom designs. Most brace designs consist of bilateral hinged uprights (posts) connected to each other by straps, rigid shells, or both. Most functional brace hinges also include variable extension stops. The braces with a rigid shell are usually custom-built and provide superior stiffness.

Functionally, braces are either passive (applying resistive loads only during abnormal motion) or active (applying active resistance at all times). Although an active design is considered more effective, some designs that attempt to provide active support may actually be applying adverse loading to remaining restraints and should be avoided.

Efficacy

Numerous studies have attempted to define the efficacy of functional braces. A few of these studies have provided significant information, but none has given definitive answers. Cawley et al[8] reviewed 44 research studies on functional brace use and concluded that "some functional knee orthoses do increase mechanical stability under low clinical loads." In contrast is the overwhelmingly positive subjective response of patients who believe that they have experienced a marked increase in knee stability with brace use. Perhaps this disparity results from our current inability to test brace function in vivo at loading rates experienced by patients or from a lack of understanding of how braces really function. For example, it is possible that braces provide mechanical cues to the muscle-control feedback systems that generate a positional or mechanical adjustment to counteract the external force applied by the brace. It is also possible that the overall effect of bracing is mediated through control of the coupled motions that characterize knee kinematics. Researchers have not yet evaluated these possibilities but have limited their studies to examine only the mechanical effects of isolated motion control. A more in-depth examination of why braces are effective is needed before we can discount the subjective positive responses of those who use them.

Recommendations

Clinical outcomes and the findings reported in the scientific literature have shown that some functional braces can limit motion and protect ligaments under specific conditions at low loads. The benefit of functional braces at higher load levels is still not understood. Brace selection should be based on the level of instability and activity of the patient. Properly fitted custom braces with rigid shells are more effective than off-the-shelf braces. However, brace choice should be based on the location and magnitude of motion created by the instability, the material properties of the brace, and economic considerations. However much care is taken in choosing the most effective brace design, the ultimate benefit will depend on the patient's being comfortable with the brace fit, understanding the limitations of the brace, and, most important, actually using the brace.

Patellofemoral Braces

Functional Characteristics

In theory, the objective of PTF bracing is to alleviate the pain associated with patellar subluxation, dislocation, or hypermobility by resisting abnormal medial and lateral patellar motion during both static and dynamic activity. Current bracing methods are not considered effective for patients suffering from PTF pain attributable primarily to chondromalacia or osteoarthritis without associated hypermobility. However, PTF braces may be beneficial for patients with a history of patellar subluxation or dislocation, complaints of pain associated with increased activity, and patellar hypermobility.

A PTF brace typically consists of an elastic sleeve or strap assembly that is placed over the knee. The brace usually contains a semicircular buttress or guide that is aligned on the side of the patella and resists lateral subluxation. One currently marketed brace (PTF, Lenox Hill Brace Company, Long Island City, NY), which was developed in our laboratory, consists of a lateral hinged arm with extension stop capability and an elastic sleeve with a patellar guide (Fig. 4). The guide is attached and controlled to some degree by straps that wrap around the leg and are attached to the ends of the lateral hinged arm. The theoretical advantage of this brace over traditional sleeve or strap assemblies is that knee extension is resisted and an active medially directed force is applied to the patella when the extension stop is functional. By resisting extension, the coupled motions of lateral patellar subluxation, an abnormal finding in functionally produced PTF pain, may be reduced.

Efficacy

In general, the etiology, diagnosis, and treatment of PTF pain are not uniformly agreed on or fully understood. There is even less agreement on the role of bracing for control of PTF pain related to patellar hypermobility. Patients have provided mixed anecdotal reports on the benefit of PTF braces. Some relief has been reported by many patients. However, rehabilitative treatments have been performed at the same time as brace use; hence, it is unclear which treatment provided the subjective benefit. Because soft materials are used in the construction of most PTF braces, mechanical testing of strength and failure has not been performed.

Clinical reports of PTF brace efficacy in the literature consist primarily of subjective evaluations of pain relief, with success rates ranging from 24% to 93%. Lysholm et al[9] reported that 21 of 24 patients exhibited a mean increase in concentric knee extension torque of 13.7% during isokinetic testing while wearing a PTF brace. Bagley[10] reported that PTF bracing with a lateral hinged-bar design provided some resistance to extension during functional activities, such as walking and going up and down stairs, but at a level not sufficient to affect actual motion limits. However, the resistance affected the magnitude and timing of activity of the vastus medialis and vastus lateralis muscles. He concluded that a neuromuscular effect resulting from a mechanical resistance cue may be operative in PTF braces. Exteroceptive inputs from the brace may trigger changes in muscle firing about the knee, increasing co-contraction for patellar stability. This effect was not seen with braces of a softer design.

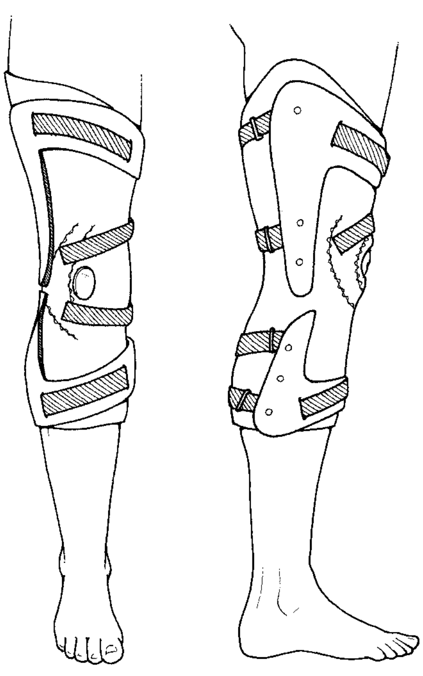

Fig. 4 A PTF brace.

Recommendations

Despite the lack of clear understanding regarding how PTF braces function in vivo, we believe that their subjective success when applied properly is sufficient to recommend their prescription. For patients with PTF pain associated with hypermobility during increased functional activity (e.g., playing sports, ascending stairs, and standing for long periods of time), a PTF brace that incorporates an extension stop may be of benefit. For acute episodes of pain, a softer, less mechanical brace coupled with rehabilitative measures for muscle strengthening may be sufficient.

Clinical Considerations in Brace Selection

The foremost concept to remember when selecting a knee brace is that each patient's knee problem is unique. Routinely prescribing a certain make or brand will not address individual problems, which will probably reduce bracing effectiveness overall.

The first step in the brace selection process is to define the patient's problem in terms of the instability or abnormal motion that the brace must control. This requires a working understanding of the functional role of knee ligaments and capsular structures and the motions controlled by each, as well as a careful examination to diagnose injury to specific structures. One must understand that diagnostic examinations for determining the magnitude of abnormal functional motion have limitations because they are conducted at low load levels. It is also important to understand the motion couplings associated with the knee and the effect of the loss of one of the soft-tissue knee restraints on the coupling relationship.

The second step is to determine the functional role of the brace and the expectations of the patient. Is the brace needed to prevent further injury, to compensate for a chronic instability due to ligamentous deficiency, or to protect a repair or reconstruction? Is the brace to be used for activities of daily living, or is it the patient's goal to return to active sports participation? The more demanding the desired increase in function and activity beyond the current injured state, the more mechanically effective the brace must be.

The third step is to provide patient education and to ensure patient compliance. Age, activity level, motivation, expectations, and rehabilitative therapy requirements all play a role in deciding which brace to recommend. A brace is more likely to be used if the patient understands its function and has some confidence in it. It is a common fallacy that a comfortable brace is working properly. If the brace is working correctly, the patient should feel resistance to abnormal motions. The patient should be educated that a period of acclimation, or "breaking in," will be necessary to facilitate functional knee stability.

Summary

On the basis of current clinical and biomechanical knowledge, we offer the following recommendations for the four types of knee braces: (1) Prophylactic braces: Single upright braces with long lever arms are most effective in reducing knee ligament forces during lateral impacts to the knee. Joint-line clearance between the brace and the knee should be maintained at all times. (2) Rehabilitative braces: Adjustable, low-cost braces that accommodate changes in leg size during the early stages of rehabilitation and/or after surgery are most desirable. These braces are most effective with "user-friendly" range-of-motion controls and an integrated locking bar-and-strap system. (3) Functional braces: Properly fitted custom braces with rigid shells have been shown to be most effective at limiting abnormal joint motion. However, individual patient considerations must be taken into account when choosing a specific brace. (4) Patellofemoral braces: For active patients who suffer from anterior knee pain that is associated with patellar hypermobility and passive genu recurvatum, a brace that incorporates an extension stop as well as a patellar motion-control device is most likely to be beneficial. However, for patients undergoing rehabilitation after acute episodes of pain, less rigid designs may be more desirable.

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