8-2011

Knee braces can decrease tibial rotation during pivoting that occurs in high demanding activities

Dimitrios Giotis
University of Ioannina

Vasilios Tsiaras
University of Ioannina

Stavros Ristanis
University of Ioannina

Franceska Zampeli
University of Ioannina

Grigoris Mitsionis
University of Ioannina

See next page for additional authors

Authors
Dimitrios Giotis, Vasilios Tsiaras, Stavros Ristanis, Franceska Zampeli, Grigoris Mitsionis, Nicholas Stergiou, and Anastasios D. Georgoulis

KNEE BRACES CAN DECREASE TIBIAL ROTATION DURING PIVOTING THAT OCCURS IN HIGH DEMANDING ACTIVITIES

Dimitrios Giotis,[1] MD, Vasilios Tsiaras,[1] PE, MSc, Stavros Ristanis,[1] MD, Franceska Zampeli,[1] MD, Grigoris Mitsionis,[1] MD, Nicholas Stergiou,[2,3] PhD, and Anastasios D. Georgoulis,[1] MD

[1]Orthopaedic Sports Medicine Center, Department of Orthopaedic Surgery, University of Ioannina, Ioannina, Greece

[2]Nebraska Biomechanics Core Facility, University of Nebraska at Omaha, Omaha, NE, USA

[3]Department of Environmental, Agricultural, and Occupational Health, College of Public Health, University of Nebraska Medical Center, Omaha, NE, USA

Correspondence to:

Anastasios D. Georgoulis, MD
PO BOX 1042
Ioannina 45110, Greece
Email: georgoulis@osmci.gr
TEL/FAX: (+30) 26510-64980

ABSTRACT

Purpose: The purpose of this study was to investigate whether knee braces could effectively decrease tibial rotation during high demanding activities. **Methods:** Using an in vivo three-dimensional kinematic analysis, 21 physically active, healthy, male subjects were evaluated. Each subject performed two tasks that were used extensively in the literature because they combine increased rotational and translational loads on the knee, (1) descending from a stair and subsequent pivoting, and (2) landing from a platform and subsequent pivoting under three conditions: (A) wearing a prophylactic brace (braced), (B) wearing a patellofemoral brace (sleeved), and (C) unbraced condition. **Results:** In the first task, tibial rotation during the pivoting phase was significant decreased in the braced condition as compared to the sleeved condition (p=0.019) and the non-braced condition (p=0.002). In the second task, the same variable was significant decreased in the braced condition as compared to the sleeved (p=0.001) and the unbraced condition (p<0.001). The sleeved condition also produced significantly decreased tibial rotation with respect to the unbraced condition (p=0.021). **Conclusions:** Bracing decreased tibial rotation in activities where increased translational and rotational forces were applied. Because knee braces decreased tibial rotation, they can possibly be used with ACL reconstructed and deficient patients to prevent such problems.

Key words: Pivoting, knee joint stability, biomechanics, patellofemoral brace, prophylactic brace

Level of Evidence: Level III, case control study

INTRODUCTION

The main function of the ACL is not only to stabilize the tibia from anterior translation relative to the femur, but also to limit excessive rotation of the tibia and to protect against varus and valgus stresses [5,6,8,9,11]. Previous in vivo studies report increased tibial rotation in ACL-deficient patients during walking [1,16]. ACL reconstruction restores tibial rotation to normative levels during walking [16]. However, Ristanis et al demonstrated in vivo that excessive tibial rotation is still present during higher loading activities and is not restored by anterior cruciate ligament reconstruction with a single-bundle technique [33]. It has been suggested that this excessive tibial rotation could degenerate soft tissues of the knee resulting in further pathologies such as knee osteoarthritis [21]. Thus, excessive tibial rotation is a problem that needs to be addressed in ACL-deficient but also in ACL reconstructed individuals when they perform higher loading activities.

According to the American Academy of Orthopaedic Surgeons Committee on Sports Medicine, knee braces are divided into four categories [15,24,43]: a) Patellofemoral braces, which are designed to reduce anterior knee pain by obstructing lateral displacement of the patella [2,27]; b) Prophylactic braces, which are designed to prevent or reduce the severity of injuries by protecting primarily the Medial Collateral Ligament and secondarily the ACL [34,36]; c) Functional braces, which are designed to provide stability to unstable knees by limiting abnormal joint motion [4,41]; d) Rehabilitative braces, which are designed to allow protected motion within a controlled range of motion.

Braces may be effective in reducing anterior translation when subjected to static or low anterior shear forces, but it is believed that braces fail to protect the knee in situations where higher loads are encountered [6,9,11,14,15,39,42]. In low and moderate activities such as running, Knutzen et al [22] and Theoret et al [37] found that the use of a functional brace in ACL deficient subjects could reduce tibial rotation. These results were also in accordance with an in-vitro study by Wojtys et al. [42] where the restraints provided by fourteen functional knee braces in six cadaveric limbs were assessed. It was found that most of the braces limited abnormal tibiofemoral displacements during rotation. However, at higher physiological forces the efficacy of braces is considered uncertain [9,11,15].

The purpose of this study was to investigate whether knee braces could effectively decrease tibial rotation in high demanding activities. An in vivo 3D kinematic analysis was performed in order to detect the effect of braces on tibial rotation, while descending or landing and subsequent pivoting. These tasks were selected because they have been used in the past to assess tibial rotation in ACL deficient and reconstructed patients [40]. Based on the available literature [37,39,42] it was hypothesized that there would be a decrease in the tibial rotation in braced knees as compared to unbraced.

MATERIAL AND METHODS

The examined group consisted of 21 physically active, healthy, male subjects (age 28.2 ± 1.4 [range 22-34 years], mass 77.3 ± 6.2 [range 62-96 kg.], height 1.78 ± 0.3 [range 1.66-1.91 m]) who had not experienced a knee injury or had any musculoskeletal or neurologic condition and had no prior experience of brace use. A clinical evaluation and recording of the Tegner score was performed in all participants by the same clinician. The score ranged from 7 to 9 which is considered normal. All subjects agreed with the testing protocol and gave their consent for participation in accordance with our University`s Medical School Institutional Review Board procedures.

Instrumentation – Procedures

Two types of braces were examined: a) the Prophylactic and b) the Patellofemoral (Figure 1). The selection of these two was done because it is easier for an athlete to use such a brace (prophylactic or patellofemoral) during an athletic event, instead of the functional or the rehabilitative brace which are heavier and restrict athletic performance considerably.

INSERT FIGURE 1 ABOUT HERE

An 8-camera optoelectronic system (Vicon, Oxford, UK) sampling at 100 Hz, was used to capture the movements of 16 reflective markers placed on selected bony landmarks of the lower extremities and pelvis using the model described by Davis et al [12]. The subjects performed two different tasks: (1) descending from a stair and subsequent pivoting, and (2) landing from a platform and subsequent pivoting. Such tasks placed combined rotational and translational loads on the knee [13,26]. These high demanding tasks were executed under three conditions: (A) Wearing a prophylactic brace (braced condition), (B) wearing a patellofemoral brace (sleeved condition) and (C) unbraced condition. The height of the platform used for landing was 40 cm and it was designed according to James et al [20]. The stairway was constructed according to Andriacchi et al [1]. All subjects were given 10 minutes to warm up and to familiarize themselves with the tasks to be performed.

During the first activity, each subject descended the stairway at their own pace. The descending period was concluded upon initial foot contact with the ground. After foot contact, the subject was instructed to pivot (externally rotate) on the landing (ipsilateral) leg at 90° and walk away. While pivoting, the contralateral leg was swinging around the body (as it is coming down from the stairway) and the trunk was oriented perpendicular to the stairway. During the second task, the subjects folded their arms across their chest and then jumped from the platform and landed with both feet on the ground. After foot contact, the subject was instructed to pivot (externally rotate) on the right or left (ipsilateral) leg at 90° and walk away. The pivoting period was identified from initial foot contact with the ground of the ipsilateral leg, until touchdown of the contralateral leg [17,31]. Each participant performed six trials for each condition for both legs. The order of the conditions was randomized.

Additionally, to validate the procedures and minimize errors reported in the literature [25,30] regarding video capture of external skin markers, an additional trial was recorded for the three examined conditions, with the subject in the anatomic position (with their feet parallel and 15cm apart). This calibration procedure allowed for correction of subtle misalignment of the markers that define the local coordinate system and provided a definition of zero degrees for all segmental movements in all planes [32,33].

Concerning the placement of the braced knee marker, a small cutout (1 cm x 1 cm) on the lateral side of the patellofemoral brace allowed the lateral femoral epicondyle marker to be placed directly on the skin during the sleeved trials. We believe that this small confined cutout did not alter the properties of the brace. Glutinus tape was used to stabilize the knee marker on the skin. The metal strap on the lateral side of the prophylactic brace could also obstruct the knee marker installation. Therefore, a knee marker, where the distance between the basis and the apex of the knee marker was 23 mm, was reconstructed. Through a small cutout (0.8 cm x 0.8cm), the knee marker was attached on the lateral femoral epicondyle.

Data Analysis and Reduction

Anthropometric measurements were combined with 3D marker data from the anatomic position trial to provide positions of the joint centers and to define anatomic axis of joint rotations [12]. Calculation of knee rotations was based on Grood et al [18]. The range of motion (ROM) during the pivoting period was used as dependent variable, which eliminated possible errors reported in the literature [35] where absolute measures (i.e. maximum or minimum) were used.

Statistical Analysis

Paired sample T-tests revealed no significant differences between the dominant and the non-dominant leg concerning both the descending and the landing tasks for our dependent variable ($t=-1.361$, $p=0.189$ and $t=-0.854$, $p=0.403$, respectively). So the dominant leg was used for further analysis. Subsequently, one way repeated measures ANOVA test was used to assess significant differences among the braced (wearing a prophylactic brace), the sleeved (wearing a patellofemoral brace) and the unbraced conditions. Post-hoc tests with the Bonferroni adjustment were applied to obtain p-values. The level of significance was set at 0.05. All statistical analyses were performed using SPSS Version 17, statistical software (SPSS, Chicago, IL).

RESULTS

Typical curves of tibial rotation during the pivoting period of a subject performing the two investigated tasks for the three conditions are shown in figures 2 and 3. The calculated range of movement that was used as the dependent variable is also identified, along with time events for all examined conditions. The intra-subject variability was in acceptable levels for all subjects with a maximum standard deviation throughout the movement being less than 4 degrees.

INSERT FIGURES 2 AND 3 ABOUT HERE

Means and standard deviations for the two tasks (descending and pivoting, and landing and pivoting) are presented for the three conditions in Table 1. In the task descending and subsequent pivoting, the mean range of motion of the tibial rotation was significantly different between the three conditions ($F=8.210$, $p=0.003$). The post-hoc analysis revealed that it was significantly less in the braced condition as compared to the sleeved ($p=0.019$) and to the unbraced condition ($p=0.002$). However, no significant differences were found between the sleeved and the unbraced conditions (n.s.) (Figure 4).

INSERT TABLE 1 AND FIGURE 4 ABOUT HERE

In the task landing and subsequent pivoting, the mean range of motion of the tibial rotation was again significantly different between the three conditions ($F=19.131$, $p<0.001$). The post-hoc analysis revealed that it was significant less in the braced condition as compared to the sleeved ($p=0.001$) and to the unbraced condition ($p<0.001$). Moreover, there were also significant differences between the sleeved and the unbraced conditions. Specifically, the mean range of motion of the tibial rotation was significantly less in the sleeved condition as compared to the unbraced condition ($p=0.021$) (Figure 5).

INSERT FIGURE 5 ABOUT HERE

DISCUSSION

The most important finding of the present study was that bracing restricted tibial rotation in high demanding activities. The efficacy of braces in reducing anterior translation or rotation has been investigated only under static or low anterior shear forces [6,9,11,14,15,31,39], but under higher physiological forces this efficacy was under dispute. In the current study, the effect of knee braces on tibial rotation was evaluated, in high demanding tasks such as (1) immediate pivoting after landing and (2) immediate pivoting after descending stairs. During these two tasks anterior and rotational loads are applied at the knee joint. It was hypothesized that there would be a decrease in the tibial rotation in the braced knee as compared to the unbraced condition.

It was found that the prophylactic brace restricted tibial rotation by nearly three degrees during the task of pivoting after descending stairs, and by approximately five degrees during the task of pivoting after landing, as compared to the non-braced condition. Moreover, it was found that the patellofemoral brace decreased the ROM of tibial rotation in the landing and subsequent pivoting task by two degrees as compared to the unbraced case. In the descending and subsequent pivoting task the difference was insignificant. The differences between the two tasks is due to the fact that during the landing task the loads that are applied at the knee, are greater than those of the descending task mostly due to the forward momentum. The results supported the hypothesis and showed that the use of bracing limited internal rotation during pivoting. Importantly, it can be hypothesized that if in healthy individuals bracing can decrease tibial rotation under the tasks used, then it is possible that in ACL deficient and reconstructed knees the usage of bracing may have the same effect. Obviously the prophylactic brace would be the brace to choose.

It should be mentioned here, that Ristanis et al found that ACL deficient and reconstructed with single bundle technique patients, presented nearly four degrees of excessive tibial rotation as compared to controls during the same task as in the present study, pivoting after descending stairs [32]. The same investigators also found that

ACL deficient and reconstructed patients exhibited six and five degrees respectively of excessive tibial rotation as compared to controls, during the other task that was used in the present study, pivoting after landing [33]. However, these in vivo studies did not examine the effect of high demanding tasks on tibial rotation, in patients reconstructed with a double bundle technique. This technique which is more sound anatomically, can resist better the pivot shift phenomenon and rotational instability than the single bundle technique [3,23,38]. However, it also comes with several drawbacks such as increased operating time [19]. Possibly, knee bracing can alleviate such problems by assisting the single bundle reconstructed patients in an area where functional deficits still exist (i.e. tibial rotation). In the current study, it was found that bracing can decrease tibial rotation by nearly 3 degrees during the task descending-pivoting and by almost 5 degrees during the task landing-pivoting. This is very important because practically bracing could potentially eliminate 75% of the excessive tibial rotation for the first task and about 80 to 100% for the second task in such patients.

A possible explanation for these results is that knee bracing may improve neuromuscular control about the knee through proprioceptive mechanisms. Perlau et al [28] found that wearing an elastic bandage improved knee joint proprioception in uninjured subjects by 25% and that this significant improvement was lost with the removal of the elastic bandage. Potentially the bandage and similarly a brace, influences afferent neural inputs to the central nervous system thus, mediating hamstrings and quadriceps activity. Branch et al [7] reported reductions in EMG activity due to bracing, for both quadriceps and hamstrings during the stance phase of side step cutting. Decreases in hamstrings activity caused by bracing, were also reported by Ramsey et al [29], during landing from a one-legged jump. On the other hand, it is also possible that these results are purely due to the mechanical properties of braces. This hypothesis could also be supported by the differences found in the present study between the two bracing conditions. Cawley et al [8] investigated biomechanically the capacity of eight different commercial knee braces and found that most of them decreased both translation and rotation as compared to the unbraced extremity under low physiological levels. Beynnon et al [5] demonstrated that functional knee bracing protects the ACL by reducing the strain values for the knee in both non-weight-bearing and weight-bearing conditions in anterior directed loading of the tibia up to 140 N. In the present study, it is uncertain if the primary reason of the reduction of tibial rotation was because the brace simply acted as a mechanical block preventing abnormal motion or if it acted by providing sensory stimuli to avoid certain stresses. Regardless the reason, the important result is that bracing can decrease tibial rotation under pivoting tasks.

However, it should be mentioned that it is possible that continuous usage of bracing could influence the muscle strength of the quadriceps femoris or the hamstrings, developing atrophy in these muscles and leading to increased knee laxity. However, this problem could be eliminated if muscular strength is closely monitored in these individuals. The results of such testing will recommend or not additional strength training to eliminate any atrophies if they occur.

General gait analysis limitations, particularly those related to the movement of skin markers [10,30] and their ability to predict bone movements are to be considered as confounding factors in the present study. The interoperator error was minimized by having the same clinician place all the markers and acquire all the anthropometric measurements. In addition, the absolute 3D marker reconstruction error of the system was very low (maximum SD, 0.303 mm; calibration space, approximately 8m^3). A standing calibration procedure was used to correct for subtle misalignment of the markers that define the local coordinate system and to provide a definition of 0° for all segmental movements in all planes. Additionally, both the dominant and the non dominant leg were examined to ensure the absence of differences in the dependent variable. Moreover, it was speculated that because the same instrumentation was used for all subjects, the level of measurement noise would be consistent for all subjects and that any differences could be attributed to changes within the system itself.

Lastly and most importantly, if in healthy individuals bracing can decrease tibial rotation under higher demanding tasks then it is possible that in ACL deficient and reconstructed, bracing may have the same result decreasing the demonstrated excessive tibial rotation and preventing further knee pathology in such patients.

CONCLUSION

In conclusion, it was found that bracing restricted tibial rotation in activities where increased translational and rotational forces are applied. However, the patellofemoral knee braces are not as effective as the prophylactic braces. Probably the improved mechanical stiffness of the prophylactic braces compared to the structure of the patellofemoral braces is the reason for this result. Future studies should examine if bracing can have a similar effect in ACL deficient and reconstructed patients where it has been found that excessive tibial rotation is a significant functional problem.

ACKNOWLEDGMENTS:

The authors gratefully acknowledge the support from the General Secretariat for Research and Technology (Operative Program Competitiveness; AKMON) to the Orthopaedic Sports Medicine Center and the Nebraska Research Initiative to Dr. Nicholas Stergiou.

REFERENCES

1. Andriacchi TP, Andersson GB, Fernier RW, et al (1980) A study of lower-limb mechanics during stair-climbing. J Bone Joint Surg Am 62:749-757

2. Aroll B, Ellis-Pegler E, Edmonds A, Sutcliffe G (1997) Patellofemoral pain syndrome: a critical review of the clinical trials on nonoperative therapy. Am J Sports Med 25:207-212

3. Bedi A, Musahl V, O`Loughlin P, Maak T, Citak M, Dixon P, Pearle AD (2010) A comparison of the effect of central anatomical single-bundle anterior cruciate ligament reconstruction and double-bundle anterior cruciate ligament reconstruction on pivot-shift kinematics. Am J Sports Med 38:1788-1794

4. Beynnon BD, Fleming BC, Churchill DL, Brown D (2003) The effect of anterior cruciate ligament deficiency and functional bracing on translation of the tibia relative to the femur during nonweightbearing and weightbearing. Am J Sports Med 31:99-105

5. Beynnon BD, Johnson RJ, Fleming BC, Pleura GD, Renstrom PA, Nichols CE, Pope MH (1997) The effect of functional knee bracing on the anterior cruciate ligament in the weightbearing and non weightbearing knee. Am J Sports Med 25;353-359

6. Beynnon BD, Pope MH, Wertheimer CM, Johnson RJ, Fleming BC, Nichols CE, Howe JG (1992) The effect of functional knee-braces on strain on the anterior cruciate ligament in vivo. J Bone Joint Surg Am 74:1298-1312

7. Branch TP (1989) Dynamic EMG analysis of anterior cruciate deficient legs with and without bracing during cutting. Am J Sports Med 17:35–41

8. Cawley PW, France EP, Paulos LE (1989) Comparison of rehabilitative knee braces. A biomechanical investigation. Am J Sports Med 17:141-146

9. Cawley PW, France EP, Paulos LE (1991) The current state of functional knee bracing research. A review of the literature. Am J Sports Med 19:226-233

10. Chambers HG, Sutherland DH (2002) A practical guide to gait analysis. J Am Acad Orthop Surg 10:222–231

11. Cook FF, Tibone JE, Redfern FC (1989) A dynamic analysis of a functional brace for anterior cruciate ligament insufficiency. Am J Sports Med 17:519-524

12. Davis R, Ounpuu S, Tyburski D et al (1991) A gait analysis data collection and reduction technique. Hum Move Sci 10:575-587

13. Decker M, Torry M, Nooman T, Riviere A, Sterett W (2002) Landing adaptations after ACL reconstruction. Med Sci Sports Exerc 34:1408-1413

14. DeVita P, Hunter PB, Skelly WA (1992) Effects of a functional knee brace on the biomechanics of running. Med Sci Sports Exercise 24:797-806

15. France EP, Paulos LE (1994) Knee bracing J Am Acad Orthop Surg 2:281-287

16. Georgoulis AD, Papadonikolakis A, Papageorgiou CD, Mitsou A, Stergiou N (2003) Three-dimensional tibiofemoral kinematics of the anterior cruciate deficient and reconstructed knee during walking. Am J Sports Med 31:75-79

17. Georgoulis AD, Ristanis S, Chouliaras V, Moraiti C, Stergiou N (2007) Tibial rotation is not restored after ACL reconstruction with a hamstring graft. Clin Orthop Relat Res 454:89-94

18. Grood ES, Suntay WJ (1983) A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng 105:136-144

19. Harner CD, Poehling GG (2004) Double bundle or double trouble? Arthroscopy 20:1015-1025

20. James CR, Bates BT, Dufek JS (2003) Classification and comparison of biomechanical response strategies for accommodating landing impact. J Appl Biomech 19:106-118

21. Kanamori A, Zeminski J, Rudi TW, Li G, Fu FH, Woo SL (2002) The effect of axial tibial torque on the function of the anterior cruciate ligament: A biomechanical study of a simulated pivot shift test. Arthroscopy 18:394-398

22. Knutzen KM, Bates BT, Hamill, J (1983) Electrogoniometry of Post-Surgical Knee Bracing in Running. Am J Phys Med 62:172-181

23. Kondo E, Merican AM, Yasuda K, Amis AA (2010) Biomechanical comparisons of knee stability after anterior cruciate ligament reconstruction between 2 clinically available transtibial procedures: anatomic double bundle versus single bundle. Am J Sports Med 38:1349-1358

24. Kramer JF, Dubowitz T, Fowler P, Schachter C, Birmingham T (1997) Functional knee braces and dynamic performance: A review. Clin J Sport Med 7:32-39

25. Lucchetti L, Cappozzo A, Cappello A, Crose UD (1998) Skin movement artefact assessment and compensation in the estimation of knee-joint kinematics. J Biomech 31:977-984

26. McNair P, Marshall R. (1994) Landing characteristics in subjects with normal and anterior cruciate ligament deficient knee joints. Arch Phys Med Rehabil 75:584-589

27. Paluska SA, McKeag MD (2000) Knee braces: current evidence and clinical recommendations for their use. Am Fam Physician 61:411-418

28. Perlau R, Frank C, Fick G (1995) The effect of elastic bandages on human knee proprioception in the uninjured population. Am J Sports Med 23:251-255

29. Ramsey DK, Wretenberg PF, Lamontagne M, Nımeth G (2003) Electromyographic and biomechanic analysis of anterior cruciate ligament deficiency and functional knee bracing. Clin Biomech 18:28-34

30. Reinschmidt C, Bogert AVD, Nigg B, Lundberg A, Murphy N (1997) Effect of skin movement on the analysis of skeletal knee joint motion during running. J Biomech 30:729-732

31. Ristanis S, Giakas G, Papageorgiou CD, Moraiti T, Stergiou N, Georgoulis AD (2003) The effects of anterior cruciate ligament reconstruction on tibial rotation during pivoting and descending stairs. Knee Surg Sports Traumatol Arthrosc 11:360-365

32. Ristanis S, Stergiou N, Patras K, Tsepis E, Moraiti C, Georgoulis AD (2006) Follow up evaluation 2 years after ACL reconstruction with bone – patellar tendon – bone graft shows that excessive tibial rotation persists Clin J Sport Med 16:111-116

33. Ristanis S, Stergiou N, Patras K, Vasiliadis HS, Giakas G, Georgoulis AD (2005) Excessive tibial rotation during high demanding activities is not restored by ACL reconstruction. Arthroscopy 21:1323-1329

34. Sitler M, Ryan J, Hopkinson W, Wheeler J, Santomier J, Kolb R, Polley D (1990) The efficacy of a prophylactic knee brace to reduce knee injuries in football. A prospective, randomized study at West Point. Am J Sports Med 18:310-315

35. Stergiou N, Bates BT, James SL (1999) Asynchrony between subtalar and knee joint function during running. Med Sci Sports Exerc 31:1645-1655

36. Teitz CC, Hermanson BK, Kronmal RA, Diehr PH (1987) Evaluation of the use of braces to prevent injury to the knee in collegiate football players. J Bone Joint Surg Am 69:2-9

37. Theoret D, Lamontagne M (2006) Study on three-dimensional kinematics and electromyography of ACL deficient knee participants wearing a functional knee brace during running. Knee Surg Sports Traumatol Arthrosc 11:555-563

38. Tsai AG, Wijdicks CA, Walsh MP, Laprade RF (2010) Comparative kinematic evaluation of all-inside single-bundle and double-bundle anterior cruciate ligament reconstruction: a biomechanical study. Am J Sports Med 38:263-272

39. Vailas JC, Pink M (1993) Biomechanical effects of functional knee bracing. Practical implications. Sports Med 15:210-218

40. Vergis A, Gillquist J (1998) Sagittal plane translation of the knee during stair walking. Comparison of healthy and anterior cruciate ligament-deficient subjects. Am J Sports Med 26:841-846

41. Wojtys EM, Kothari SU, Huston LJ (1996) Anterior cruciate ligament functional brace in sports. Am j Sports Med 24:539-546

42. Wojtys EM, Loubert PV, Samson SY, Viviano DM (1990) Use of a knee-brace for control of tibial translation and rotation. A comparison, in cadavera, of available models. J Bone Joint Surg Am 72:1323-1329

43. Wright RW, Fetzer GB (2007) Bracing after ACL reconstruction. A systematic review. Clin Orthop Relat Res 455:162-168

FIGURE LEGENDS

Figure 1

The two types of braces that were used in the present study: a) the Prophylactic (braced condition) and b) the Patellofemoral (sleeved condition).

Figure 2

A tibial rotation curve during the period under study for a full “stride” from a representative healthy subject regarding the unbraced, sleeved and the braced conditions in descending stairs. A stick figure describing the descending and subsequent pivoting task, accompanies the diagram.

Figure 3

The landing and subsequent pivoting task with unbraced, sleeved and the braced conditions. A stick figure describing the task also accompanies the diagram.

Figure 4

Maximum ROM of tibial rotation

Box-plots that demonstrate the mean and SD values for range of motion (ROM) of the tibial rotation during the pivoting period of the task descending stairs and pivoting. The asterisk (*) indicates statistical significant differences.

Figure 5

Maximum ROM of tibial rotation

Box-plots that demonstrate the means and standard deviations for range of motion (ROM) of the tibial rotation during the pivoting period of the task landing and pivoting. Significant differences are indicated with an asterisk (*).

TABLE LEGENDS

Table 1

Means and standard deviation (SD) values for range of motion of the tibial rotation during the pivoting period for the two tasks investigated for the braced (wearing a prophylactic brace), the sleeved (wearing a patellofemoral brace) and the unbraced conditions.