Research article

Arthrometric evaluation of stabilizing effect of knee functional bracing at different flexion angles

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Abstract

Previous in-vivo investigations on the stabilizing efficacy of knee bracing for ACL reconstructed patients have been often limited to 20-30 degrees of knee flexion. In this study, the effectiveness of a uniaxial hinged functional brace to improve the knee stability was assessed at 30, 60 and 90 degrees of knee flexion. Arthrometry tests were conducted on 15 healthy subjects before and following wearing the brace and the tibial displacements were measured at up to 150 N anterior forces. Results indicated that functional bracing has a significant stabilizing effect throughout the range of knee flexion examined ($p < 0.05$). The rate of effectiveness, however, was not consistent across the flexion range, e.g., 50% at 30 degrees and only 4% at 90 degrees. It was suggested that accurate sizing and fitting as well as attention to correct hinge placement relative to the femoral condyles can limit brace migration and improve its effectiveness in mid and deep knee flexion. With using adaptive limb fittings, through flexible pads, and a polycentric joint a more significant improvement of the overall brace performance and efficacy might be obtained.

Key words: Functional brace, knee, ACL injury, instability, arthrometery.

Introduction

Anterior cruciate ligament (ACL) injuries are among the most frequent problems faced by knee clinicians (Kupper et al., 2006). Numerous techniques have been proposed in the literature for treatment of knee instabilities caused by ACL injury; their indications and effectiveness, however, remain controversial (Ellenbecker, 2000). Wearing functional orthotic knee braces is known as a prime conservative treatment for management of mild knee instabilities related to ACL partial rupture, as well as for improving joint stability during the healing period following ACL reconstruction (Hofmann et al., 1984).

The efficacy of functional bracing on knee stability has been assessed by several researchers using different techniques. Some of these studies have focused on cadaver specimens, considering the fact that the standard manual clinical tests for knee stability, e.g., pivot shift, Lachman, and anterior drawer tests, are difficult and

sometimes impossible to be applied on brace wearing subjects (Baker et al., 1987; Hofmann et al., 1984; Wojtys et al., 1987; 1990). These works, however, might be rationally criticized for not including the knee physiological loading conditions and the in-vivo behavior of ligamentous and muscular soft tissues. Others have tried to evaluate the stabilizing effect of knee bracing in-vivo, using radiographic measurement of the tibiofemoral relative displacement (Jonsson and Karrholm, 1990) or direct measurement of ACL strain, during anterior-posterior laxity testing (Baker et al., 1987; Fleming et al., 2000; Wojtys et al., 1990).

The most widely used method to assess the efficacy of knee bracing in-vivo has been the arthrometry test in which a device is externally strapped to the lower leg and the tibial translation is recorded during anterior shear loading (Beck et al., 1986; Branch et al., 1988; Colville et al., 1986; Mishra et al., 1989; Rink et al., 1989; Risberg et al., 1999). All of the previous arthrometric studies in the literature, however, have examined the knee stability behavior at a limited flexion range of 20-30 degrees, probably due to the design restrictions of the commercially available arthrometers. While this is reasonable for conventional arthrometry, as a diagnostic method for evaluating ACL functional integrity, it is not sufficient for evaluation of functional knee bracing where a knee stability improvement across the whole range of knee flexion is to be examined. The objective of the present study was to evaluate the efficacy of a standard widely used hinged functional brace to improve the knee stability across the range of knee flexion, i.e., at 30, 60, and 90 degrees, using arthrometry.

Methods

Fifteen healthy volunteers, including 8 females and 7 males, with an average age of 24 years (ranged between 18 and 28) participated in this study. They had normal ranges of motion and muscle strengths and no history of lower limb pathology. Prior to testing, all participants read and signed an informed consent form approved by the university's Human Investigations Committee.

Each subject was tested, before and following knee bracing, using a home-made arthrometer at 30, 60 and 90 degrees of knee flexion. The arthrometer had a design similar to KT 2000 system (MedMetric, San Diego, USA) and was equipped with an S-Beam load cell (DBBP se-

ries, Bongishin, China), a rectilinear displacement transducer (PY3, Gerfran, Italy), and a data acquisition card (6024E, National Instruments, USA). The reliability of the arthrometer was examined in previous studies and a variability of less than 1.6 mm at 150N force was revealed in the 90% confidence limit (Heydari et al., 2008; Soudbakhsh et al., 2005). The knee functional brace tested consisted of rigid side supports, adjustable uniaxial hinges, straps, foam padding, and contoured posterior plastic thigh and calf supports. It had basically only one degree of freedom through the hinge joint which provided rotation in the sagittal plane and allowed the knee to be flexed to different flexion angles. However, some laxity in other directions was also provided by the brace due to its non-rigid attachment to the limb. With proper adjustment, sizing, and fitting, the brace could prevent the knee joint from hyperextension and limit the external knee rotation and anteroposterior joint translation. These simple orthotic braces are usually used as a prime conservative treatment for management of mild knee instabilities related to ACL partial rupture as well as for strain-shielding of a reconstructed ACL during the healing period (Hofmann et al., 1984). Two braces in small and large sizes were used to fit the individuals' left legs.
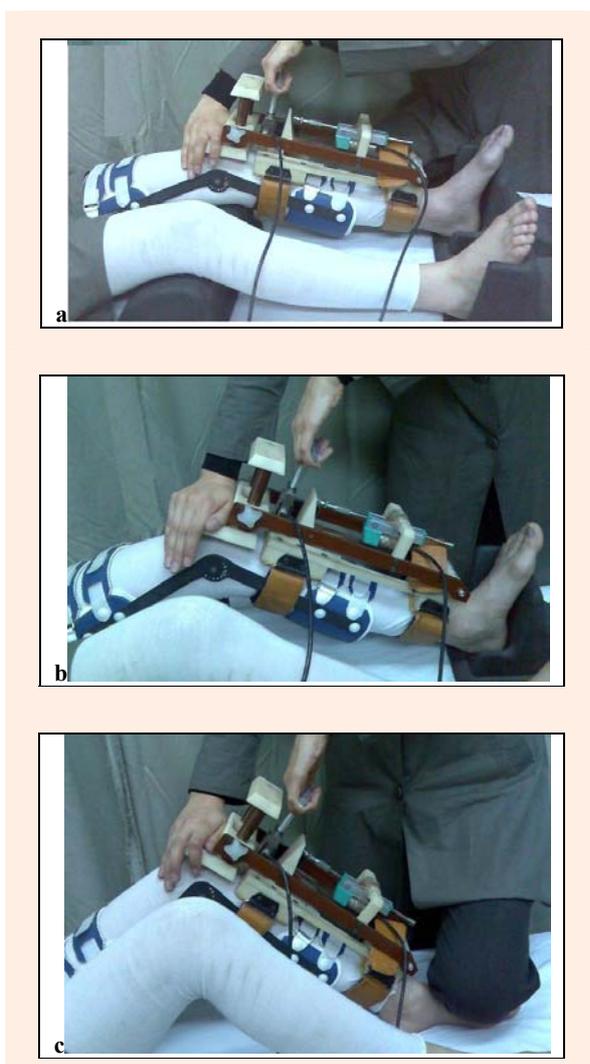

Figure 1. Arthrometry test configurations at (a) 30 degrees, (b) 60 degrees and (c) 90 degrees of knee flexion.

Braced and non-braced trials were conducted in supine position, with subject's hands at his sides, on a comfortable firm examining table. At 30 and 60 degrees knee flexion, the subject's knees were maintained symmetrically in place using a thigh support platform at a level proximal to the popliteal space (Figure 1a, b). A foot support platform was also used to keep the feet with the tibia at approximately 15 degrees external rotation. At 90 degrees flexion, the feet were positioned on the table so that the tip toes were at the level of the foot support, and the examiner prevented limbs movement by sitting on subject's feet (Figure 1c). At each flexion angle, the arthrometer was positioned on the tibial crest and secured with two Velcro straps. The lower border of the patellar pad was adjusted to be at the same level of the proximal part of patellar tendon so that with pushing the patellar pad in posterior direction, the patella was maintained firmly in the femoral groove throughout the examination (Figure 1a-c). With the patella well stabilized against the femur, the relative movement of the tibiofemoral joint was measured as the relative motion between the patellar and tibial sensor pads of the arthrometer.

All tests were conducted by a single experienced examiner. During testing, the individual was asked to keep his leg muscles relaxed. This was assured by palpating the calf muscles gently by the examiner. Furthermore in three pretest repetitions, forces of up to 90N were applied in anterior and posterior directions alternatively. The main tests were performed by application of an increasing anterior force up to 150N to the tibia and the resulting displacements were measured. Three tests were conducted at each flexion angle and if there was any evident difference between trials, they were repeated by subject's consent.

The arthrometric force-displacement data were imported to a PC for further processing and statistical analysis. The results of the 3 trials of each flexion angle were averaged using Spline curve fitting in MATLAB (Mathworks Inc., Natick, Massachusetts). The means and standard deviations of displacement data for braced and non-braced tests were calculated at 30, 60, 90, 120 and 150 Newton force levels and paired t tests (at 5% level) were used to determine if the results were significantly different. All statistical analyses were conducted using SPSS statistical software package (version 11, SPSS Inc, Chicago, IL).

Results

In general, the joint stability increased with knee bracing for all the three flexion angles examined. At 30 degrees knee flexion, the means of the tibial displacements of the 15 subjects in non-braced tests were 3.1 (± 0.9 SD), 4.7 (± 1.2 SD), 5.9 (± 1.6 SD), 7.1 (± 2.1 SD), and 8.6 (± 2.6 SD) millimeters, respectively, under 30, 60, 90, 120, and 150 Newton anterior force levels. Following knee bracing, these were reduced to 1.4 (± 0.7 SD), 2.0 (± 1.1 SD), 2.7 (± 1.3 SD), 3.5 (± 1.7 SD), and 4.4 (± 1.0 SD) millimeters, respectively (Figure 2a). Paired t tests revealed that these differences were statistically significant at all force levels examined ($p < 0.05$).

At 60 degrees knee flexion, the differences of the tibial displacements for non-braced and braced conditions were only significant at 120 N and 150 N ($p < 0.05$). The means of the displacements were obtained to be 7.8 (± 2.6 SD), and 9.9 (± 3.0 SD) millimeters, respectively, for the non-braced tests, in comparison with 6.6 (± 2.3 SD), and 8.3 (± 2.4 SD) millimeters, respectively, for the braced tests (Figure 2b). With the knee flexed at 90 degrees, smaller tibial displacements were obtained compared to 30 and 60 degrees knee flexion. Statistical comparison of braced and non-braced results at 90 degrees flexion revealed that the anterior displacement reduced significantly following bracing only at 150 N force level ($p < 0.05$). The means of the tibial displacements were 5.8 (± 1.8 SD) and 5.3 (± 1.5 SD) millimeters, respectively, for non-braced and braced conditions (Figure 2c).
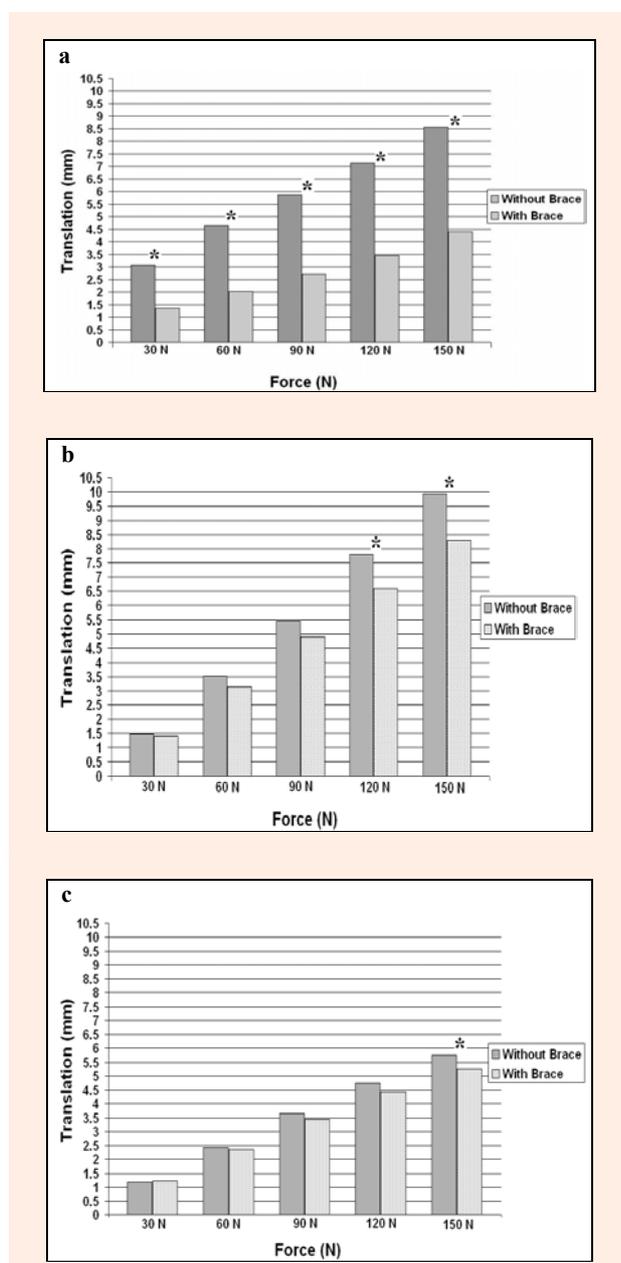

Figure 2. Comparison of tibial translations due to different anterior forces in non- brace and bracing conditions at **(a)** 30 degree, **(b)** 60 degree, and **(c)** 90 degree of knee flexion. * indicates that there is a significant difference.

Discussion

During arthrometry, it is important that the patella is well stabilized against the femur, so that the relative movement of the tibiofemoral joint is measured as the relative motion between the patellar and tibial sensor pads of the arthrometer. This is achieved in the available arthrometer systems through proper adjustment of the device and pushing on the patellar pad in posterior direction to ensure that the patella is maintained firmly in the femoral groove throughout the examination. If the knee flexion angle is less than 20º or the femoral sulcus angle is abnormally wide, the restraints will not be sufficient and the patellar mobility might produce test errors (Kupper et al., 2006). However, at higher knee flexions, with the patella well-seated in the femoral groove, the larger joint force due to the closure of the angle between the patellar and quadriceps tendons, and the increasing passive tension of the muscles (Farahmand et al., 1998; 2004), the patella is firmly maintained within the groove and its mobility is minimized. Moreover, as is illustrated in Fig 1a-c, the risk of the tibiofemoral relative movement is reduced at higher knee flexion angles due to the fact that the anterior drawer force applied to the tibia becomes less oblique in relation to the direction of the femoral shaft. Therefore, in general, there is no problem in using arthromteres at mid and deep knee flexion angles except that with the patella seated deeply in the femoral groove, a smaller patellar posterior surface is available for contacting with the patellar pad. Thus, in spite of pushing against, the pad might slide over the patella during the test producing some test errors. This was avoided in our tests using a slightly concave patellar pad which provided higher conformity and larger contact area with the patellar posterior surface.

The standard knee configuration for arthrometric diagnosis of knee instability, however, is the flexion range of 20º to 35º (Branch et al., 1988; Bach et al., 1995; Heydari et al., 2008). This is due to the fact that the knee instability is most prominent and can best manifest itself in this flexion range (Bach et al., 1995; Markolf and Amstutz 1976; Markolf et al., 1978). As a result, previous in-vivo arthrometric investigations concerning the efficacy of functional bracing on the knee stability have also been conducted in this flexion range (Branch et al., 1988; Colville et al., 1986; Mishra et al., 1989; Rink et al., 1989). Mishra et al (1989) evaluated four designs of knee braces at 30 ± 5° of knee flexion and reported that the anterior tibial displacement decreased in braced conditions. Rink et al (1989) assessed the stabilizing efficacy of three functional braces on 14 ACL deficient subjects at 20 to 30 degrees flexion angle and reported that all braces provided statistically significant improvement of knee stability. Colville et al (1986) examined the effectiveness of a functional knee brace for treatment of knee instability at 20 degree of flexion and reported that at 100 N anterior force, the tibial displacement decreased by 29% following bracing. Finally, Branch et al (1988) compared the restraining effect of two kinds of knee braces at 25 and 90 degree of knee flexion and found significant improvement of knee instability at 89 N anterior force. However, their results indicated that under active anterior drawer test with higher loading forces, neither of braces was effective

in controlling anterior tibial translation.

The results of the previous studies generally support the hypothesis that functional bracing improves the knee stability significantly. However, considering the fact that the stability examination has been often limited to up to 30 degrees knee flexion in previous studies, it remains a question that whether this improvement is limited to knee extension and early flexion angles, or it is maintained during mid and deep flexion. The results of our study suggest that functional bracing has a significant effect across the range of knee flexion angles examined; however, the rate of this effectiveness is not consistent. At 30 degrees knee flexion (Figure 2a); the knee stability increased significantly by about 50% following bracing, regardless of the amount of anterior force. Similar results of 29-40 percent increase of knee stability have been reported by Mishra et al., (1989) and Wojtys et al., (1996). At 60 and 90 degrees knee flexion, however, the stabilizing effect of knee bracing was less considerable (11 percent at 60 degrees and 4 percent at 90 degrees) and appeared to be statistically significant only at higher force levels (Figure 2b, c).

Another interesting finding of the present study was the pattern of variation of the knee stability with flexion angle following bracing. For non-braced condition, the knee stability was least at 30 degrees flexion and improved with increasing flexion angle, similar to what reported by previous investigations (Markolf and Amstutz 1976; Markolf et al., 1978). However, following bracing, the least stability was appeared to be related to 60 and then 90 degrees knee flexion.

In order to justify these findings, one has to consider the functional bracing characteristics and the arthrometry test conditions in more detail. First of all, a uniaxial hinge brace, as used in this study, cannot adapt itself with the changing instantaneous axis of rotation of the knee to support the joint firmly in throughout the range of flexion. Furthermore, knee braces are often molded to fit the subjects' legs at 15 to 20 degrees of knee flexion. So, at higher flexion angles they might stand more freely on the limb due to the change of the soft tissue volume. This loose attachment at high flexion angles is thought to make the anterior force to be completely transferred to the limb at low force levels. However, at higher forces the tibial displacement exceeds the gap and the force is partly transferred to the brace, hence the stabilizing effect of brace appears.

The above considerations suggest that attention to correct hinge placement relative to the femoral condyles is necessary to improve the overall brace performance and efficacy. Also, accurate sizing and fitting can limit brace migration and improve its effectiveness. Some design modifications might be also suggested to improve the efficacy of knee bracing at mid and deep knee flexion, e.g., using adaptive limb fittings through more flexible pads, and/or polycentric joints.

Conclusion

There have been some limitations in our study which needs to be addressed. The anterior force was limited to up to 150 N in our study for the sake of safety of the vol-

unteer subjects. In weight bearing and physiological conditions, however, much higher shear loads are expected to be applied to the knee. Therefore, the stabilizing effect of knee braces in mid and high flexion angles might be more significant in physiological conditions than what observed in the arthrometry tests of this study. Further studies are needed to evaluate theses suggestions. Moreover, we tested healthy subjects instead of ACL reconstructed patients. Although no significant difference has been reported in mechanical endurance and stiffness properties of normal ACLs and successfully healed ACL grafts by previous studies (Fleming et al., 2000; Risberg et al., 1999), more realistic results may be obtained if ACL reconstructed patients are examined.

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Key points

- Functional bracing improves the knee joint stability mostly in extension posture.
- Unlike the non-braced condition, the least knee joint stability appears in mid and deep flexion angles when using a hinged brace.
- Accurate sizing and fitting and attention to correct hinge placement relative to the femoral condyles can limit brace migration and improve its effectiveness in mid and deep knee flexion.
- The overall brace performance and efficacy might be improved significantly using adaptive limb fittings through flexible pads and/or polycentric joints.

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