Effects of knee bracing on postural control after anterior cruciate ligament rupture

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ABSTRACT

Study design: Randomized clinical trial.

Objectives: To investigate the effects of functional knee braces on postural control in patients with anterior cruciate ligament (ACL) rupture.

Background: ACL rupture leads to both mechanical knee instability and deficits in proprioception. Although elastic knee braces do not increase mechanical stability, patients report improved stability when wearing a brace. Elastic braces were found to reduce the loss of proprioception. It is, however, still unclear whether they also improve postural control, which involves the processing of proprioceptive input at a higher level.

Methods: We studied 58 patients with isolated unilateral ACL rupture using computerized dynamic posturography and compared overall stability index (OSI) scores for injured and uninjured legs with and without a knee brace. In addition, patients were classified as copers and non-copers depending on knee function.

Results: Within subjects, OSI scores were 3.0±1.1° for uninjured legs when unbraced, 2.8±1.3° for uninjured legs when braced (p=0.17), 3.7±1.5° for unbraced injured legs, and 2.9±1.3° for braced injured legs (p<0.001). For the injured legs of copers and non-copers, OSI scores were 3.4°±1.2° for copers and 4.0°±1.6° for non-copers in the unbraced condition (p=0.11) and 2.7±1.0° for copers and 3.1±1.4° for non-copers in the braced condition (p=0.26).

Conclusion: Elastic knee braces increase postural stability by approximately 22% in patients with ACL rupture. There was no difference in postural stability between uninjured and injured legs in the braced condition. One possible explanation is that bracing improves both proprioception and postural control.

Level of evidence: Controlled clinical trial, level 2a.

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1. Introduction

1.1. Functions of the anterior cruciate ligament (ACL)

ACL rupture is one of the most serious sports-related injuries and the most common ligamentous knee injury [41]. In the majority of cases, surgical ACL reconstruction is indispensable for the restoration of the function and stability of the injured knee joint. This is particularly necessary because of the two main tasks of cruciate ligaments. Apart from a purely mechanical function, i.e. the ligamentous control of tibial translation in the ventral direction and rotation, the ACL also plays an important role in knee joint proprioception. Surgical ACL reconstruction not only restores mechanical stability after a period of healing and remodeling but also allows patients to more efficiently train knee joint proprioception and restore neuromuscular control [3,4,6,17,43]. The greatest challenge for physicians and patients alike is to improve the neuromuscular control system and achieve adequate coordination of movement. After successful surgery, patients must undergo a long period of intensive rehabilitation and exercise in order to achieve satisfactory postoperative knee joint proprioception and muscular control [21,28].

1.2. Proprioception and postural control

The cruciate ligaments were previously believed to act only as passive mechanical stabilizers, but their important contribution to knee joint proprioception is now well recognized [4,5,10,12,24,27]. The processing of proprioceptive, visual and vestibular afferent inputs from the periphery at the spinal and cerebral levels is termed postural control. After successful surgery, patients must undergo a long period of intensive rehabilitation and exercise in order to achieve satisfactory postoperative knee joint proprioception and muscular control [21,28].
and walk safely without falling. The complexity of this neuromuscular control process was shown in a study by Reed-Jones and Vallis [36], who found that steering control of locomotion was altered in patients with limited lower limb proprioceptive feedback. Whereas healthy subjects used a steering synergy initiated by the head and followed by the trunk and extremities in order to reorient the whole body in response to a disturbance of movement, patients with an ACL rupture reoriented body segments at the same time.

Depending on their ability to compensate for subjective instability, patients can be classified as copers or non-copers. This classification is based on a study by Chmielewski et al. [9] and distinguishes between patients who are able to reach their pre-injury level of performance despite the absence of an ACL and those who are not. Whereas copers do not experience a loss of knee function during normal everyday activities, non-copers complain of a feeling of knee instability and describe giving-way symptoms that considerably affect daily activities. This phenomenon can be explained by differences in thigh muscle control and a deterioration of mechanical properties of the joint. An example of this is the ACL-hamstring reflex. In physiological terms, tibial translation evokes a biphasic reflex response of the hamstring muscles, i.e. a short-latency response (SLR) and a medium-latency response (MLR) [15]. An ACL rupture is generally associated with an increase in the MLR on the affected side. A comparison of the MLRs of copers and non-copers reveals a further significant increase in the MLRs of non-copers. This delay in sensorimotor control is one reason for giving-way symptoms [16]. It is interesting to note that there are patients who are better able to compensate for a torn ACL (copers) than other patients who complain of a marked feeling of knee instability (non-copers) although both groups of patients sustained the same type of injury. For this reason, we compared both subgroups and investigated whether this feeling of instability can be objectively assessed by computerized dynamic posturography (CDP). If we were able to show that functional knee braces provide more benefit to non-copers than to copers, this finding should be reflected in treatment decisions.

1.3. Effects of knee bracing

The majority of patients with ACL rupture complain of an increased instability of the injured leg, which is preoperatively managed with an elastic knee brace. Patients wearing this type of knee support, which does not limit the range of motion of the affected knee and does not mechanically stabilize the capsuloligamentous structures, report an improvement in proprioception [22]. It is already known that elastic knee braces provide benefit to patients with meniscal lesions and posttraumatic patella dislocation [23,30]. In addition, elastic braces have a positive influence on joint proprioception not only in patients with ACL rupture but also in healthy subjects [7,8,22,24,33]. In the literature, increased intracapsular pressure is suggested as a possible reason for this effect. Joint effusion and the resulting rise in intracapsular pressure, for example, lead to an increase in proprioception [11]. This finding requires, however, that the knee be examined in a pain-free condition despite the presence of effusion. Thijs et al. [42] too, investigated whether the restoration of original intracapsular pressure is the reason for increased proprioception, not least because the joint capsule contains a multitude of mechanoreceptors.

In addition, we know from our own unpublished data that postural control decreased by 23.3% in legs with ACL rupture when compared with healthy legs.

It is still unclear whether, and if so to what extent, elastic knee braces influence postural control at the cerebral and spinal levels in patients with anterior cruciate ligament rupture. The purpose of this prospective clinical experimental study was therefore to investigate the effect of knee bracing on the postural control of patients with ACL rupture and to compare injured and uninjured legs.

2. Methods

2.1. Patients

Sixty-five patients took part in the study (age: 26.5 ± 8.0 years, height: 175.9 ± 23.1 cm, weight: 82.3 ± 11.5 kg). Of these, 60 were male and 5 were female. Diagnostic and therapeutic arthroscopy and ACL reconstruction were indicated in all patients on the basis of a clinical examination and an MRI investigation of the affected knee joint. A medical history was taken and a standardized examination of the musculoskeletal system was conducted. Computerized dynamic posturography (CDP) was then performed. The following day, all patients underwent arthroscopic ACL reconstruction. During this procedure, the presence or absence of ACL rupture was definitely demonstrated. During preoperative MRI and diagnostic/therapeutic arthroscopy, we took great care to confirm that the patient had only isolated unilateral ACL rupture in order to exclude possible influences of comorbidities or other factors (e.g. meniscus injuries or cartilage damage) on postural control. An injury or a disease of the contralateral uninjured knee was excluded on the basis of the medical history, a clinical examination and clinically relevant knee scores such as the Tegner score, the Western Ontario and McMaster Universities Arthritis (WOMAC) score, the Knee Outcome Survey for Activities of Daily Living (KOS-ADL) and Sports Activities (KOS-Sport) scores, the Knee Society Score (KSS), and the Lysholm score. We were thus able to rule out the presence of additional injuries especially in non-copers. In this context, it is noteworthy that we showed in a previous study that meniscal lesions had no influence on postural control. All patients who met the inclusion and exclusion criteria (Table 1) were then ultimately enrolled in the study. Six patients were excluded since they were found to have an additional injury to structures of a lower extremity (e.g. a previous rupture of the contralateral ACL). In one patient, arthroscopy revealed the presence of an intact anterior cruciate ligament. Accordingly, a total of 58 patients (54 men, 4 women; age: 25.9 ± 7.6 years; height: 175.8 ± 24.4 cm; weight: 81.9 ± 12.0 kg) remained in the study. Only seven patients were older than 30 years. There are two explanations for this low number. First, ACL ruptures are most commonly seen in physically active men. Second, our hospital is a military facility that provides care for a large number of young male patients.

All participants gave their written informed consent to take part in this study, which was approved by the ethics committee of the University of Ulm (No. 284/09) and was conducted as part of a special research project of the German Armed Forces (16K3-S-100712) in accordance with the Declaration of Helsinki of 1964.

Table 1

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
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<tr>
<td>Written informed consent from the patient</td>
<td>Other diseases of the lower extremities, spine or pelvis, especially injuries to the capsuloligamentous structures of the affected knee</td>
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<td>Minimum patient age of 18 years</td>
<td>Pain at rest in the affected joint which would influence measurements</td>
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<td>Unilateral ACL rupture, functional ACL insufficiency, scarring of the anterior cruciate ligament to the posterior cruciate ligament</td>
<td>Rerupture and/or previous ACL surgery</td>
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<td>Healthy contralateral knee joint</td>
<td>Underlying metabolic or neurological disorder</td>
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<td>Long-term medications (other than oral contraceptives)</td>
</tr>
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<td></td>
<td>Diseases of the audiovisual system</td>
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<td></td>
<td>No arthroscopy</td>
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</table>
2.2. Computerized dynamic posturography (CDP)

Postural stability was assessed with a Biodex Stability System® (Biodex, Shirley, New York) (Fig. 1A). This system is purported to be a reliable tool for dynamic posturography tests. Measurement reliability was confirmed in several studies [1,31,32,35]. The Biodex Stability System has a circular unstable platform that permits up to 20° of tilt in any plane and has a measuring accuracy of 0.1°. An integrated computer records the degree of displacement from the initial level under dynamic conditions and calculates a score for the medial–lateral stability index (MLSI), the anterior–posterior stability index (APSI) and the overall stability index (OSI) in degrees. The OSI was the main variable in our study and the basis for the sample size calculation. Higher stability index scores indicate poorer stability, and lower scores indicate better stability. Since Level 8 is used in most studies, we selected this setting for our tests in order to facilitate the comparability of our results with available and future data. During the tests, we covered the Biodek computer screen in order to eliminate feedback from the monitor [31].

2.3. Functional knee brace

We used a StabiloGen® Eco knee brace (Bort, Weinstadt-Benzach, Germany) (Fig. 1B), which is a commercially available patella stabilizing brace with silicone pads. According to the manufacturer, this brace has a wide range of indications for use including patellar instability, joint effusion, swelling, osteoarthritis and other types of arthritis, postoperative irritation, and ligament stability. In our opinion, this brace was well suited for our study on account of this wide range of indications for use.

2.4. Procedures

We instructed each subject to stand barefoot on the platform in order to rule out any adverse effects of footwear on measurement results [34,37]. Prior to each measurement, one foot was positioned in the center of the platform. This position remained unchanged during the entire measurement process. All participants performed three 20-second trials at Level 8 on both the injured and uninjured legs in the braced and unbraced conditions. Average stability scores were calculated from these trials. Prior to the measurements, factors such as body height, regular sports activities and gender were found to have no influence [31,40]. In our highly homogeneous patient sample, the contralateral healthy legs served as controls. Possible or proven effects of age, height and weight on stability index scores could therefore be ignored [40].

2.5. Differentiation between copers and non-copers

Not only did we compare the injured and uninjured legs in the braced and unbraced conditions but we also differentiated between copers and non-copers on the basis of the following criteria [18]:

- Presence or absence of giving-way symptoms
- Limitations in performing normal everyday and sports activities as a result of the loss of knee function which were assessed with the Knee Outcome Survey for Activities of Daily Living (KOS-ADL) and Sports Activities (KOS-Sport)
- Clinical evaluation of knee function using the Knee Society Score (KSS).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>StabiloGen</th>
<th>Eyes open</th>
<th>Mean</th>
<th>SD</th>
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<th>95% CI (upper bound)</th>
<th>Min</th>
<th>Max</th>
<th>p-value (t-test)</th>
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<td>OSI</td>
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<td>3.7</td>
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<td>3.4</td>
<td>4.1</td>
<td>1.3</td>
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<td></td>
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<tr>
<td></td>
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<td>1.1</td>
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<td>3.3</td>
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<td>4.5</td>
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<td></td>
<td>ACL rupture (braced)</td>
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<td>2.6</td>
<td>3.3</td>
<td>−0.6</td>
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<tr>
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<td>No ACL rupture (braced)</td>
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<td>0.2</td>
<td>−2.4</td>
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<td></td>
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<tr>
<td></td>
<td>No ACL rupture (unbraced)</td>
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<td>0.9</td>
<td>1.8</td>
<td>2.3</td>
<td>0.5</td>
<td>5.3</td>
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<tr>
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<td>Differences</td>
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<td>1.4</td>
<td>1.9</td>
<td>0.4</td>
<td>5.1</td>
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</table>

Fig. 1. The Biodex Stability System (A) and the StabiloGen® Eco knee brace (B).
On the basis of these criteria, 25 patients (24 men, 1 woman; age: 25.2 ± 6.8 years; weight: 79.9 ± 10.0 kg; height: 172.3 ± 36.1 cm) were identified as copers and 33 patients as non-copers (30 men, 3 women; age: 26.5 ± 8.2 years; weight: 83.5 ± 13.2 kg; height: 178.4 ± 8.1 cm). We included these subgroups in the statistical analysis. Since this subgroup analysis was performed in an exploratory manner, the results can provide only indicative evidence. The required sample size was calculated for a comparison of patients with and without ACL rupture, which was the primary objective of this study.

2.6. Statistical analysis

In cooperation with the Institute of Biometrics at the University of Ulm, Germany, the required sample size was calculated. Based on experience, the effect size of clinical importance for the OSI score, which was the main variable in our study, was assumed to be 0.5°. The sample size required to reject the null hypothesis there is no difference between injured and uninjured legs was 58 subjects (nQuery). We thus took into account not only the clinical importance of a possible difference between the two groups but also the measuring accuracy of the system, which is 0.1° and is clearly below the expected effect size of 0.5°. The sample size was calculated for a comparison of injured and uninjured legs with and without a knee brace. It was not adjusted to a comparison of copers and non-copers, which was only a secondary objective of this study.

In addition to descriptive statistics, we used t-tests for dependent and independent samples to calculate the statistical significance of differences in OSI, MLSI and APSI scores between injured and uninjured legs. A p-value of less than 0.05 was considered statistically significant. SPSS 17.0 software was used for statistical analysis.

Fig. 2. A–C. Stability index scores (OSI = overall stability index, APSI = anterior–posterior stability index, MLSI = medial–lateral stability index) in degrees and levels of significance during eyes-open testing. The use of a knee brace led to an increase in postural control of up to 22% (t-test). An asterisk (*) indicates where the difference was found to be significant.
Since we randomized the sequence of the tests (uninjured with/without a knee brace, injured with/without a knee brace) and compared the braced and unbraced conditions, our study meets the requirements of a Level 2 study.

3. Results

3.1. Significant improvement in postural control in the braced condition

For injured legs, the overall stability index (OSI) score was 3.7±1.5° without a knee brace and 2.9±1.3° with a knee brace (p<0.001). Postural control thus increased by 21.6% in the braced condition. For uninjured legs, the OSI score was 3.0±1.1° with the knee unbraced and 2.8±1.3° with the knee braced (p=0.17).

When the subjects did not wear a knee brace, we found a significant difference between the OSI scores for injured legs (3.7±1.5°) and uninjured legs (3.0±1.1°) (p<0.001). By contrast, a comparison of the OSI scores for the injured legs (2.9±1.3°) and uninjured legs (2.8±1.3°) in the braced condition did not reveal a significant difference (p=0.43).

The APSI and MLSI scores are provided in Table 3 and in Fig. 3A-C.

3.2. Comparison of copers and non-copers

The OSI score was 3.4±1.2° for copers and 4.0±1.6° for non-copers in the unbraced condition (p=0.11). By contrast, the OSI score was 2.7±1.0° for copers and 3.1±1.4° for non-copers in the braced condition (p=0.26).

The APSI and MLSI scores are given in Table 3 and in Fig. 3A-C.

Within the group of copers, the OSI scores improved from 3.4±1.2° without a knee brace to 2.7±1.0° with a brace (p<0.001). This corresponds to an increase of 20.6%. By comparison, copers had an OSI score of 4.0±1.6° without a knee brace and 3.1±1.4° with a knee brace (p<0.001). In this group, the use of an elastic knee brace thus led to an increase in stability of 22.5%.

Our results suggest that there was no significant difference in postural control between copers and non-copers either in the braced or in the unbraced condition. Nevertheless non-copers tend to show poorer stability than copers. Within both groups, however, we were able to prove that the use of a knee brace led to a significant increase in postural stability. This effect was slightly greater in the group of non-copers (22.5%) than in the group of copers (20.6%) (p=0.26).

4. Discussion

The objective of our study was to assess whether elastic knee braces improve postural control in patients with ACL rupture.

We were able to show for the first time that knee bracing leads to a marked increase in postural control by approximately one fifth of the original level in the injured leg. In the preoperative period, the use of elastic knee braces can thus increase postural control to a level similar to that of the uninjured leg in patients with ACL rupture.

ACL ruptures are known to cause a loss of neuromuscular afferent input from the knee [4,5,10,12,24,27]. We know from our own unpublished data, that this loss of information also influences postural control, which involves the processing of information and the coordination of movement at the central level on the basis of proprioceptive information from the periphery of the body and afferent input from the visual and vestibular systems. Wearing an elastic knee brace significantly compensates for this deficit of afferent information or, in other words, for the loss of joint proprioception [8,22,26]. One possible explanation is the increase in intracapsular pressure that is associated with external joint compression by a brace. Similarly, Ferrell et al. [11] reported an improvement in proprioception in the presence of joint effusion. This is consistent with our work on meniscal allograft transplantation where the restoration of hemostasis and the original intracapsular pressure was the reason for increased proprioception. Our findings prove that this effect on joint proprioception also applies to postural control. The use of an elastic knee brace led to an increase of approximately 22% in postural control, which had been reduced as a result of ACL rupture. Knee bracing improved postural control to a level similar to that of the uninjured leg. Since we did not find a significant difference between uninjured legs in the braced and unbraced conditions, we can conclude that a knee brace can fully compensate for the deficit in postural control after ACL rupture.

In an earlier study [30], we were able to prove that functional knee braces have also a positive effect on postural control in patients with meniscus injuries. In these subjects, OSI scores improved by approximately one sixth. The effect of a knee brace was thus smaller than in patients with ACL rupture. Jerosch and Prymka [25] found no effect at all of knee bracing on proprioception in patients with meniscal lesions.

One possible explanation for these results is that the main task of the ACL is to stabilize the knee whereas the primary functions of the menisci are to ensure joint congruency, the optimum distribution of stress in the joint, and shock absorption. The ligaments tightly control and guide the joint and thus ensure mechanical knee stability. A neuromuscular feedback loop provides functional knee stability and contributes to the maintenance of postural control [5,27,43,44]. As already demonstrated in an earlier study [29], the different types of functions of these two structures can sufficiently explain the absence of a difference in postural control between legs with and without meniscal lesions. In addition, we were able to show that meniscal lesions do not influence the hamstring reflex after tibial translation. For this reason, it is unclear whether the menisci are involved in the neuromuscular control loop [14]. This helps further explain why bracing has a lesser effect on stability in patients with meniscal injuries.

Although many patients with ACL rupture are preoperatively managed with rigid knee supports that provide mechanical stability, elastic knee braces, too, were found to significantly increase postural control. Elastic braces and mild compression of the joint thus not only improve knee joint proprioception but also make a considerable contribution to the compensatory increase in postural control. The results that we obtained in our subgroup analysis support this
hypothesis. We differentiated between copers and non-copers on the basis of functional ability during sports and normal everyday activities and the presence or absence of giving-way symptoms [18]. This approach allowed us to detect a greater effect of knee bracing in non-copers. Hurd and Snyder-Mackler [20] found that non-copers stabilized their injured knee with a strategy involving less knee motion and higher muscle contraction. In addition, non-copers – compared with copers – are known to use different movement patterns and have poorer sensorimotor control of their thigh muscles after tibial translation [15,16,38]. Functional knee braces appear to improve the ability of non-copers to compensate for the loss of stability by compressing the joint and supporting muscle contraction (functional stabilization). The absence of a significant difference between copers and non-copers is likely to be the result of an inadequate sample size, which had not been calculated for a comparison of these groups. This comparison was only a secondary objective of this study.

We used an elastic knee brace and not an orthosis that mechanically stabilizes the joint and limits the range of motion of the affected knee. Such orthoses are primarily used in patients with additional injury to the collateral ligamentous structures. For this reason, we believe that the improvement of postural control is indeed the result of an increase in functional stability (i.e. joint proprioception) rather than mechanical stability. This assumption is supported by the results of other authors who investigated the effect of elastic braces on knee joint proprioception. In a study by Jerosch et al. [26] for example, subjects with ACL rupture underwent different sports tests such as single-leg jumping that require a high level of proprioceptive

Fig. 3. A–C. Stability index scores (OSI = overall stability index, APSI = anterior–posterior stability index, MLSI = medial–lateral stability index) in degrees for copers and non-copers during eyes-open testing with and without a knee brace (t-test).
feedback from the periphery of the body and found that the application of an elastic knee brace led to a significant improvement in proprioception. Beynnon et al. [7,8] reported in their studies that the joint position sense in subjects with ACL rupture improved when the patients wore an elastic knee brace. One limitation of our study is that we did not specifically investigate knee joint proprioception. Other research groups, however, showed in several studies that proprioception is considerably reduced in patients with ACL rupture. Beadd et al. [5] for example, measured an increase in reflex hamstring contraction latency after tibial translation in ACL-deficient knees and found a correlation between this increase in latency and the frequency of giving way episodes. They assumed that the effert pathways to the hamstring muscles were intact and postulated that the loss of proprioceptive input was one of the reasons for the increase in reflex hamstring contraction latency. Barrack et al., Corrigan et al., Jerorsch and Prymka, and Kataya et al. focused their studies on the afferent aspects of proprioception. Using angle reproduction tests and different proprioception and coordination exercises for the lower limbs, they found that proprioceptive feedback from the knee joint was considerably reduced after ACL rupture [4,10,12,24,27]. In an earlier, previously unreleased study involving the use of the Biodex Stability System, we were able to show that this loss of feedback leads to a deficit in postural control. We have now shown that elastic knee braces can significantly improve both knee joint proprioception and the ability to control posture.

5. Conclusion

We were able to show for the first time that the use of a functional knee brace in patients with isolated unilateral ACL rupture increases postural control in the affected leg to a level similar to that of the uninjured leg. In our opinion, this improvement is primarily the result of an increase in joint proprioception, which is considerably reduced in patients with ACL lesions. These findings have several implications for clinical practice:

- ACL rupture is associated with a significant impairment of postural control, which is reflected in a subjective feeling of knee instability reported by many patients.
- Commercially available functional knee braces effectively improve knee instability after ACL rupture. For this reason, we advise patients with ACL rupture to preoperatively wear functional braces with a view to increasing postural control, preventing falls, and supporting immediate post-traumatic neuromuscular training.
- In patients with isolated ACL ruptures, we do not generally recommend the use of mechanical orthoses, which are sometimes much too expensive. Wearing an elastic knee brace is often sufficient to considerably improve the functional component of the feeling of knee instability.

Patella stabilizing braces do not increase mechanical stability and do not limit the range of motion of the affected knee. For this reason, decisions on how to stabilize the joint preoperatively must be made on an individual basis especially for patients with additional injuries such as a collateral ligament rupture.

6. Key points

6.1. Findings

Our study showed for the first time that the use of a functional knee brace in patients with isolated unilateral ACL rupture increases postural control, which involves the processing of proprioceptive input at a higher level, and thus improves the ability to maintain balance. Knee bracing increases postural control in the affected leg to a level similar to that of the uninjured leg.

6.2. Implication

Wearing an elastic knee brace is often sufficient for patients with isolated ACL rupture to considerably improve postural control before surgery. These patients do not necessarily need mechanical orthoses, which are more expensive and less comfortable to wear.

6.3. Caution

Our subgroup analysis, which was intended as a pilot study, does not allow us to draw definitive conclusions about the effects of knee braces in copers and non-copers. In addition, we only studied patients with isolated ACL rupture. We therefore recommend that patients with additional injuries such as a collateral ligament rupture should still be managed with mechanical orthoses.

7. Conflict of interest

No conflict of interest exists.

References


