Effect of Brace Design on Patients with ACL-Ruptures

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Key words
- ACL-deficiency
- functional bracing
- proprioception
- rehabilitation

Abstract

Different designs of functional knee braces for ACL-injury rehabilitation exist. In addition to the mechanical stabilization provided by rigid shell braces, sleeve braces also address proprioceptive mechanisms, but little is known if this leads to benefits for ACL-deficient subjects. Therefore the aim of this study was to investigate the effect of 2 different functional brace designs (shell and sleeve brace) on functional achievements in ACL-deficient patients. 28 subjects with ACL-ruptured knees performed tests for knee joint laxity, joint position sense, static and dynamic balance and isometric and dynamic lower limb extension strength in non-braced, sleeve braced and shell braced condition. The results showed a significant decrease in knee joint laxity for sleeve (33 %; $p<0.001$) and rigid shell bracing (14 %, $p=0.039$). The sleeve brace revealed a significant increase in dynamic balance after perturbation (20 %; $p=0.024$) and a significant increase in dynamic lower limb peak rate of force development (17 %; $p=0.015$) compared to the non-braced condition. The effects might be caused by the flexible area of support and the incorporated mechanisms to address proprioceptive aspects. Braces might not be needed in simple daily life tasks, but could provide beneficial support in more dynamic settings when patients return to sporting activities after an ACL-injury.

Introduction

ACL injury is the most frequent knee injury. Approximately 100 000 ACLs are torn each year in the USA alone, 70 % of which occur during athletic activity [34] .The importance of the anterior cruciate ligament (ACL) lies in the stabilization of the knee joint as well as in its proprioceptive functions [5, 16, 31]. Hence, an injury of the ACL implies functional loss in both stability and proprioception [38].

The primary goal of ACL injury treatment is to regain functional stability during knee joint motion with optional resumption of sporting activity. Currently 2 stabilizing approaches after ACL injuries exist: The knee joint laxity can be reduced either mechanically through surgical reconstruction of the ACL or by improving the neuromuscular control of the knee joint with specific training programs such as strength and proprioceptive training without reconstructing the ACL [1, 12, 39]. In assistance of both approaches functional knee braces can be applied to either protect the operated leg (surgical treatment) or support stabilization as long as knee stability is not yet regained (conservative treatment), respectively. Additionally, functional knee braces might be used in specific situations (e.g., sporting activity), if the rehabilitation process fails and patients still experience knee instability [27]. These patients are referred to as non-copers or ACL-deficient subjects.

Traditionally functional knee braces are designed as rigid shell braces with a hinge joint and straps to mechanically guide and support the knee joint during motion. Studies reported initial short term positive effects for bracing (reduced pain, less swelling), but no differences in long-term rehabilitation between braced and non-braced ACL-reconstructed patients [24, 31]. For ACL-deficient knees research showed that rigid functional braces are able to reduce tibial displacement in low-load conditions. This was not the case for high-load conditions as they may appear in active patients [4, 37]. Even more explicitly, the in vivo study by Ramsey et al. [28] revealed no differences for ACL-deficient patients in the anterior tibial displacement between rigid shell

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braced and non-braced conditions in a dynamic situation. On the other hand, ACL-deficient individuals with functional knee bracing change their gait pattern in order to reduce the knee extensor moment during the stance phase [13]. While some patients report discomfort using these braces [31,35], other patients report subjective benefits such as a higher sense of stability or increased performance [6,36].

As there are no consistent findings whether or not rigid functional bracing is beneficial in the rehabilitation of the ACL-deficient and ACL-reconstructed knee, the discussion for brace use remains controversial. It seems that the sole mechanical stabilization might not be enough to support an instable knee joint. Additional approaches to enhance functional knee braces need to be considered in order to better fulfil their stabilization task. Sleeves might have the potential to improve the neuromuscular control by increasing the proprioception of the knee surrounding muscles. Beneficial effects of sleeves on proprioception have already been demonstrated in healthy subjects [2,32], and in subjects with different types of knee disorders [5,33], but only a few studies have been conducted focusing on ACL-reconstruction and none on ACL-deficient knees.

For patients with ACL-reconstruction neoprene sleeves and rigid functional braces had similar effects on the patients' results in functional tests [6]. Mayr et al. [23] reported a superior effect of a water-filled sleeve brace over a shell brace regarding effusion, swelling, extension deficit and patient compliance. In a healthy population Singer and Lamontagne [35] found that subjects wearing a sleeve brace showed a more similar gait pattern compared to unbraced walking as when wearing a rigid shell brace. Even though the reported effects of a sleeve brace seem beneficial little evidence is available whether a sleeve brace is able to support patients with ACL-deficient knees. Additionally, different sleeves showed in a knee simulator a lower ability to mechanically stabilize the knee. One exemption was the sleeve brace SofTec Genu (Bauerfeind, (Inc., Zeulenroda-Triebes, Germany) which showed mechanical stability data similar to rigid shell braces [22]. Therefore this brace combines the mechanical characteristics of a traditional rigid shell brace with the proprioceptive characteristics of a sleeve. Yet, it remains unknown, how this design affects the joint laxity of ACL deficient subjects. Besides decreasing static joint laxity a functional brace mainly needs to support the patient during motion. Hence, research focusing on the effect of different functional knee brace designs on functional achievements such as proprioception, postural control and strength needs to follow for ACL-deficient individuals. Therefore, the aim of this study was to investigate the effect of a shell brace and a sleeve brace on passive knee joint laxity and functional achievements in ACL-deficient patients.

Methods
▼

Subjects

28 ACL-deficient subjects (16 female, 12 male; age: 40 ± 13 years) with non-operated, ruptured ACL knees participated in this study. The time of the ACL rupture occurred between 3–360 months (median: 7 months, Q_{25}: 3 months, Q_{75}: 36 months). Even though the time of rupture was between 3–360 months, all subjects were non-copers and experienced "giving way" episodes repeatedly. Inclusion criteria were defined as: (a) age between 18–60 years, (b) unilateral tear of the ACL without reconstruction, (c) time of rupture at least 3 months ago, (d) instability of the knee determined through (d1) side-to-side difference in knee laxity ≥ 3 mm evaluated via the KT-1000^{TM} arthrometer (MEDmetric, San Diego, California[a]), (d2) functional instability measured via a hop test [14] (index of symmetry > 85 %) and (d3) at least one "giving way" since ACL rupture, (e) no injuries of the posterior cruciate ligament, (f) contralateral side must be free of injuries. The study was approved by the ethics board and informed consent was signed by all subjects participating in the study. Additionally, this study has been performed in accordance with the ethical standards proposed by Harriss and Atkinson [18].

Braces and preparation

Subjects were provided with a sleeve brace (SofTec Genu, Bauerfeind Inc., Zeulenroda-Triebes, Germany) (**Fig. 1a**) and a shell brace (4Titude Donjoy, ORMED GmbH, Freiburg, Germany) (**Fig. 1b**). Both braces were fitted individually by an orthopedic technician and subjects were familiarized with the correct positioning of the braces. All subjects came to the laboratory for 2 habituation sessions prior to the actual measurements to reduce learning effects. The data was then collected in 2 testing sessions of 1 ½ h to avoid fatigue effects. A restricted randomization scheme was set up for randomizing the order of braces, order of sessions and tests. During each session the tests were first performed in one condition (sleeve brace, shell brace, non-braced) before the subjects continued to the next condition. Each session had its specific tests, but the order of the tests was randomized within the session, as well as which session was first to be completed.

Testing protocol

Static anterior laxity was measured using the KT-1000^{TM} arthrometer[a] [19] with an applied force of 98 N.

Joint position sense was measured using the angle reproduction test [20]. Subjects were seated with the feet hanging free and visual sight was blinded by an eye mask. A goniometer was used to measure the knee angle. The injured leg was moved to a random target knee angle between 0° and 90° by the tester and was held in position for 3 s by the subject. After bringing the leg into a neutral position the subjects had to recapture the target knee angle. Postural control was analyzed by testing static and dynamic balance. Static balance was identified by the following tests: (a) single leg stance on a stable surface with eyes closed (AMTI, model BP600900, Advanced Mechanical Technology, Watertown, MA, 1000 Hz[b]) (**Fig. 2a, b**) single leg stance on a 2-dimensional free moving platform (Posturomed, Haider Bioswing, Pullenreuth[c], [25]) (**Fig. 2b**). Dynamic balance was identified by the tests (c) single leg stance on a 2-dimensional free moving platform after a 2.5 cm lateral perturbation (Posturomed[c]), (d) landing on a force plate (AMTI[b]) after a 30 cm forward single leg jump and (e) landing on a force plate (AMTI[b]) after a 30 cm forward single leg jump with a 90° inward turn around the longitudinal axis (**Fig. 2e**). The specific recording times are reported in **Table 1** and have been identified in pretests.

Injured lower limb strength was analyzed in bilateral isometric and dynamic conditions. Maximum isometric lower limb extension strength was tested on an instrumented leg press equipped with 2 side by side force plates (self-construction, 1000 Hz[e]) (**Fig. 2d**). Subjects were positioned with a knee angle of 60° (anatomical angle) and each foot was placed on a separate force plate. Subjects were instructed to press with maximum effort

Fig. 1 **a** Sleeve brace (SofTec Genu, Bauerfeind Inc., Zeulenroda-Triebes, Germany); **b** rigid shell brace (4Titude Donjoy, ORMED GmbH, Freiburg, Germany).

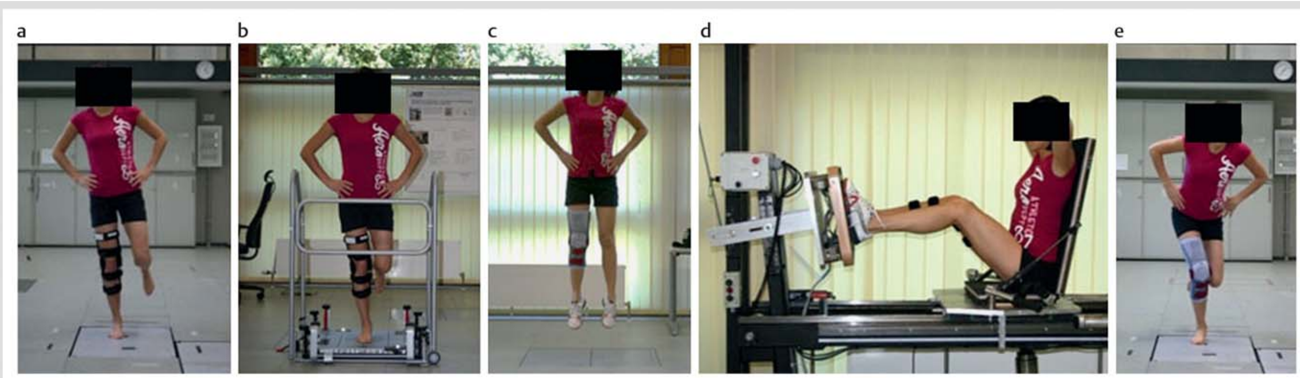

Fig. 2 **a** single leg stance on stable surface with eyes closed, **b** single leg stance on instable surface, **c** CMJ. **d** isometric lower limb extension strength, **e** landing after a 30 cm forward single leg jump with a 90° inward turn around the longitudinal axis,

for 3 s. Dynamic lower limb strength was measured using the counter-movement jump (CMJ) as common test in sports performance diagnostics [3]. Subjects performed the counter movement jumps (CMJ) with arms akimbo on a left-right-separated force platform (self-construction[e]) (▶ **Fig. 2c**). Force dependent variables were normalized to body weight. The specific test criteria for all tests are reported in ▶ **Table 1**. For the static and dynamic balance tests unfortunately not all subjects managed to complete valid tests in all 3 conditions, hence the data for the respective test was excluded for the specific subject. The actual number of subjects (N) for each test can be found in ▶ **Table 2**.

Statistical analysis

Statistics were calculated with SPSS 17.0 using a one-way repeated measure ANOVA including Bonferroni adjustments. The level of significance was set at $p \leq 0.05$. Necessary requirements for normality and sphericity were given. Effect size was calculated using partial eta^2 (η^2_p) (borders: $\eta^2_p = 0.01$: small, $\eta^2_p = 0.06$: medium, $\eta^2_p = 0.14$: high effect sizes) [7,9]. Post-hoc tests were calculated to assess pair-wise comparisons for parameters showing a significant difference. Cohen's d (d) [10] with pooled standard deviation was calculated for effect sizes for each pair-wise comparison and was quantified to be small for $d < 0.40$, medium between 0.40–0.79 and high with effect size $d \geq 0.80$.

Results

Mean (95%-CI) values of test parameters and respective p-values and effect sizes are presented in ▶ **Table 2**.

Significant differences between the 3 conditions were identified for knee joint laxity, single leg stance on an unstable lateral perturbed platform (path length, standard deviation of anterior-posterior and medio-lateral displacement), landing after a single leg forward jump with 90° inward rotation (standard deviation of anterior-posterior and medio-lateral displacement) and CMJ (rate of force development).

Table 1 Specific testing criteria and parameters.

test	parameter	trials	trials taken into calculation
KT 1000			
	tibial displacement	3	mean
angle reproduction test			
	absolute difference between target angle and recaptured angle	10	mean
postural control – single leg stance			
a) stable surface, closed eyes (10 s)	path-length (COP-AMTI) sd of pl in ant.-post. direction sd of pl in med.-lat. direction		
b) posturmoed, open eyes (15 s)	path-length (COM of standing platform) sd of pl in ant.-post. direction sd of pl in med.-lat. direction	5	mean of the 3 intermediate trials (in terms of path length)
c) posturomed, perturbation (4 s: start 1 s after perturbation)			
d) landing after 30 cm forward single leg jump (5 s)	path-length (COP-AMTI) sd of pl in ant.-post. direction sd of pl in med.-lat. direction		
e) landing after 30 cm forward single leg jump with 90 ° turn (5 s)			
isometric lower limb strength			
	peak force (F_{peak})	3	trial with highest Fmax
CMJ			
	jump height (h) peak force (F_{peak}) peak RFD (RFD_{peak})	3	trial with maximum jump height

sd: standard-deviation, pl: path-length, CMJ: Counter-movement-jump, RFD: rate of force development

More specifically, knee joint laxity (KT-1000) was significantly reduced by 33 % with sleeve bracing and by 14 % with rigid shell bracing. Additionally, knee joint laxity reduction was significantly higher using a sleeve brace than the shell brace, which is also supported by the effect sizes.

The single leg stance on an unstable laterally perturbed platform revealed similar medium effect sizes for all tested parameters for the sleeve and the shell brace, indicating a reduction of postural sway. Significant differences were only identified for the sleeve braced condition though. A significant reduction of 20 % for the path length and for the standard deviation of the displacement in anterior-posterior (16 %) as well as for the mediolateral (23 %) direction could be observed.

The 3 conditions showed a significant effect in the ANOVA in the landing after a single leg forward jump with a 90 ° inward turn (regarding the anterior-posterior and medio-lateral standard deviation of displacement), but level of significance was not reached in the post-hoc tests. For both braces medium effect sizes indicate a reduction in postural sway compared to the non-braced condition.

The CMJ revealed that subjects wearing a sleeve brace significantly increased the rate of force development in the injured leg by 17 % compared to the non-braced situation and by 19 % compared to the shell braced condition.

All other tests showed no effects of the braced conditions compared to the non-braced condition.

Discussion

Little is known about the effect which brace designs, that also address proprioceptive mechanisms, impose on ACL-deficient patients [6, 23, 35]. Therefore the aim of this study was to investigate the effect of different brace types compared to a non-braced condition on joint laxity and functional tests for proprioception, stability and strength in ACL-deficient patients.

Even though generally similar effects between the 2 brace designs occur in this subject group, significant differences between the sleeve and the shell brace were identified for the knee joint laxity and the production of rate of force development in the CMJ. The latter described the ability to generate strength within a short period of time and is important for a fast stiffening of the muscle which leads to an active stabilization of the joint [17].

The effect of the sleeve brace can be explained by 2 mechanisms: (1) The sleeve brace covers a substantially larger surface area of skin compared to the shell brace and the non-braced condition. Proprioception might be increased due to this larger skin-contact area of the sleeve brace, allowing additional cutaneous stimulation and an increase of the afferent inflow of cutaneous receptors [8, 15, 16, 30, 32]. (2) Additionally, the sleeve exerts pressure on the underlying muscles and joint capsules and therefore might stimulate the muscle spindles and golgi tendon organs of the underlying muscles [33]. Both mechanisms allow feedback for motor control and might consequently improve dynamic joint stability. This has been reported in studies addressing healthy patients (e. g., [2, 8, 15, 30, 32]) and in studies focusing on patients with patello-femoral pain [33], but has not yet been shown for ACL-deficient subjects.

In practice this could explain the significant differences in reduced knee joint laxity and increased rate of force development compared to the shell brace.

Since proprioceptive benefit seems to be related to the proprioceptive demand of the task [8], the more simple tasks of this study, might not have evoked the need for additional proprioceptive information. In the complex situation of the CMJ and perturbed stance, however, the sleeve brace might have enhanced the stimulation of the subcutaneous sensors and provoked the occurring effect. Therefore more dynamic situations should be considered in future studies. This is especially of interest for the subgroup of patients, who wants to return to sporting activity, at which high dynamic loading and weight-transits

Table 2 Mean (95 %-CI) values of functional tests with corresponding p-values and effect size (η^2_p) for ANOVA and effect sizes of post-hoc tests (Cohen's d).

test parameter	N	non-braced (95 %-CI)	sleeve (95 %-CI)	shell (95 %-CI)	p^* (e^2)	p^*: no brace sleeve (d)	p^*: no brace shell (d)	p^*: sleeve shell (d)
KT 1000								
98 N [mm]	28	8.3 (1.3)	5.6 (0.7)	7.1 (1.1)	< 0.001 (0.46)	< 0.001 (0.94)	0.039 (0.37)	0.001 (0.36)
angle reproduction test								
mean abs difference [°]	28	2.5 (0.5)	2.3 (0.4)	2.4 (0.3)	0.762 (0.01)	–	–	–
stable surface, eyes closed								
path length [m]	23	1.01 (0.14)	1.01 (0.15)	0.98 (0.13)	0.822 (0.01)	–	–	–
sd_ ant.-post. [mm]	23	11.8 (1.0)	11.1 (1.2)	11.6 (0.6)	0.907 (0.00)	–	–	–
sd_med.-lat. [mm]	23	11.0 (1.1)	11.2 (1.0)	11.1 (0.6)	0.440 (0.03)	–	–	–
unstable surface								
path length [m]	25	0.45 (0.08)	0.46 (0.13)	0.47 (0.14)	0.901 (0.00)	–	–	–
sd_ ant.-post. [mm]	25	0.9 (0.1)	0.9 (0.2)	0.8 (0.2)	0.992 (0.00)	–	–	–
sd_med.-lat. [mm]	25	1.5 (0.3)	1.5 (0.4)	1.6 (0.3)	0.932 (0.00)	–	–	–
unstable surface, perturbation								
path length [m]	24	0.25 (0.10)	0.20 (0.08)	0.21 (0.08)	0.026 (0.15)	0.024 (0.54)	0.179 (0.44)	1.000 (0.10)
sd_ ant.-post. [mm]	24	4.1 (1.6)	3.4 (1.32)	3.5 (1.33)	0.035 (0.14)	0.047 (0.46)	0.153 (0.40)	1.000 (0.06)
sd_med.-lat. [mm]	24	1.6 (0.6)	1.3 (0.4)	1.4 (0.36)	0.005 (0.22)	0.009 (0.76)	0.104 (0.57)	0.752 (0.26)
landing single leg forward jump								
path length [m]	26	0.62 (0.07)	0.60 (0.06)	0.64 (0.04)	0.411 (0.04)	–	–	–
sd_ ant.-post. [mm]	26	17.0 (2.1)	16.5 (1.8)	18.4 (1.7)	0.373 (0.04)	–	–	–
sd_med.-lat. [mm]	26	8.9 (20.9)	8.8 (20.9)	9.5 (10.7)	0.075 (0.12)	–	–	–
landing single leg forward 90 ° jump								
path length [m]	25	0.75 (0.06)	0.74 (0.07)	0.70 (0.05)	0.059 (0.11)	–	–	–
sd_ ant.-post. [mm]	25	19.6 (2.0)	18.5 (1.1)	17.8 (1.7)	0.022 (0.16)	0.128 (0.49)	0.061 (0.68)	0.820 (0.01)
sd_med.-lat. [mm]	25	11.7 (1.1)	11.1 (1.0)	10.3 (0.9)	0.045 (0.12)	0.121 (0.52)	0.149 (0.53)	1.000 (0.18)
isometric force, leg press								
F_{peak} [N/BW]	28	2.15 (0.24)	2.19 (0.25)	2.22 (0.26)	0.420 (0.03)	–	–	–
counter movment jump (CMJ)								
jumping height [m]	28	0.24 (0.04)	0.26 (0.03)	0.25 (0.04)	0.312 (0.05)	–	–	–
F_{peak} [N/BW]	28	1.04 (0.04)	1.06 (0.05)	1.04 (0.05)	0.073 (0.10)	–	–	–
RFD_{peak} [N/s/BW]	28	5.98 (0.70)	7.02 (1.11)	5.88 (0.90)	0.003 (0.22)	0.015 (0.42)	1.00 (0.04)	0.016 (0.21)

sd: standard deviation, ant-post: anterior-posterior direction, med-lat: medio-lateral direction, F: force, RFD: rate of force development. *level of significance ≤ 0.05

challenge the musculoskeletal system and the importance for the ability to produce strength in a short period of time increases substantially.

This study provided the first stage to investigate the effects of different brace designs in ACL-deficient subjects. The used tests focused on loads applied well below those that might occur in sporting tasks or cause injury, but still covered a range of different complexity levels in the active situations. It seems that subjects do not need to use the support of the functional braces in relatively static and simple tasks. At more coordinative complex situations such as the perturbed single leg stance or the landing after a jump with an inward turn it is indicated that braces provide a stabilizing effect. It is speculated that this effect increases with more dynamic tasks, e. g., at sporting activity.

Muscle activation plays a major role in knee stabilization and various studies have addressed the matter of quadriceps and hamstring activation patterns for ACL-injured subjects using braces [26, 29, 37]. Unfortunately, the sleeve brace does not allow measurements of muscle activation via surface electromyography without changing the properties of the brace, therefore effects on muscle activation cannot be reported in this study.

The inhomogeneous group of subjects in terms of age, activity level and time of ACL rupture might be a limitation of the study, but reflects the group of patients clinics treat in daily life. Since it has been suggested that bracing might have different effects in early and late rehabilitation [11, 21], an evaluation with the time of ACL rupture as covariance was performed and showed no significant effect on the results.

Furthermore, it has to be noted that the subjects used the different braces solely for testing, therefore only short time effects can be reported. Additionally it has to be considered that only one type of rigid shell and one type of sleeve brace were examined. Therefore, the results cannot be generalized since different braces might have revealed different findings [4].

Conclusion

▼

The sleeve and the shell brace generally reveal similar effects on functional achievements, such as a significant reduction of knee joint laxity and a tendency to decrease postural sway in a perturbed situation and after a jump with a 90 ° rotation. The sleeve brace showed in most test conditions higher effect sizes and increased the rate of force development at the CMJ. The effects might be caused by the flexible area of support and the incorporated mechanisms to address proprioceptive aspects. Therefore, including proprioceptive elements in a functional brace could be favorable over solely providing mechanical stabilization. The effects, however, were only observed in complex coordinative situations. Braces might not be needed in simple daily life tasks, but could provide beneficial support in more exposed situations or when patients return to sporting activities after an ACL injury.

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