Journal of Exercise Science & Fitness 16 (2018) 94–98

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Custom-made hinged knee braces with extension support can improve dynamic balance

Akira Ochi*, Hiroshi Ohko, Susumu Ota, Nami Shimoichi, Tsukasa Takemoto, Kaho Mitsuke

Division of Physical Therapy, Faculty of Care and Rehabilitation, Seijoh University, 2-172 Fukinodai, Toukai-City, Aichi, 476-8588, Japan

ARTICLE INFO

Article history:
Received 21 November 2017
Received in revised form
20 August 2018
Accepted 29 August 2018
Available online 4 September 2018

ABSTRACT

Background/Objective: We investigated whether custom-made hinged knee braces can facilitate knee extensor and flexor strength and influence functional performance as compared with other knee braces.
Methods: We enrolled 28 healthy young participants with no history of physical activity or brace use. The participants executed functional performance tests under the following 5 conditions: 1) without a knee brace, 2) wearing a knee sleeve, 3) wearing a hinged knee brace without assistance, 4) wearing a knee brace with extension support (KBE), and 5) wearing a knee brace with flexion support (KBF). The KBE and KBF were custom-made hinged knee braces equipped with rubber tubes. The functional performance tests performed assessed maximal isokinetic strength, single-leg jumping height/distance, anterior and posterior reach distance on a single leg, and dynamic balance ability.
Results: The benefit of the custom-made hinged knee brace was observed only during the anterior reach distance on a single leg. The KBE allowed a significantly greater single-leg anterior reach distance when compared to that in the no brace condition. There was a significant relationship between the improvement in the single leg anterior reach distance with KBE and the changes in isokinetic knee extension with KBE compared to the no brace condition. With regard to other parameters, there were no differences compared with the use of other knee braces and thus no apparent benefit.
Conclusion: Our findings suggest that using a KBE enhances performance during dynamic balance activity in individuals who benefit from improved knee extension strength.

Introduction

Fabric-based knee braces and prophylactic braces are prescribed for instability following bone or soft tissue injuries to the knee.[1] Hinged knee braces were reported to increase dynamic balance and landing stability after a jump during locomotion and when performing athletic tasks.[2] Some reports also suggested that hinged knee braces improve proprioception in the knees of patients with anterior cruciate ligament injuries.[1,3–5] These findings suggested that wearing hinged knee braces increases proprioceptive input around the knee and improves functional performance involving dynamic balance ability. However, wearing the prophylactic knee brace may inhibit the functional performance of healthy participants, such as speed during the forward sprint, because of decreased peak torque, and torque acceleration energy.[6] The effect of braces on functional performance remains unclear, including in activities such as the one-leg hop, figure-of-eight run, stair climbing, walking, cutting, agility runs, straight running, and bicycle ergometry.[7]

Invasive surgeries of the knee such as anterior cruciate ligament reconstructions often causes imbalance of muscular strength, such as altered hamstrings-to-quadriceps ratio.[8,9] In addition, those undergoing invasive surgeries of the knee may exhibit decreased functional performance tests including hopping and balance tasks.[10–12] Therefore, it was thought that external support for a poorly functioning knee to compensate for impaired muscular strength was necessary after injury or surgeries. The development of a new, easy-to-use assistive device for poor knee function and flexion and extension support is needed.

Recently, greatly improved mechanical efficiency was observed based on the elasticity of rubber that led to the development of hinged knee braces that can assist in extending and flexing the knee.[13] The available evidence suggests that these braces reduce

* Corresponding author.
E-mail addresses: ochi@seijoh-u.ac.jp (A. Ochi), ohko-h@seijoh-u.ac.jp (H. Ohko), ota-s@seijoh-u.ac.jp (S. Ota), r1320159@gmail.com (N. Shimoichi), 1320225@gmail.com (T. Takemoto), 1320381@gmail.com (K. Mitsuke).

https://doi.org/10.1016/j.jesf.2018.08.002

the knee adduction moment during gait and can provide flexion support during the swing phase in patients with osteoarthritis.[13] Hinged knee braces with extension and flexion support are able to maintain or increase joint torque, in contrast with common knee braces that only improve joint position sense through proprioceptive input.[14–16] Thus, hinged knee braces may improve functional performance involving muscle strength, single leg jumping, and/or dynamic balance.

The purpose of the present study was to investigate whether hinged knee braces with assistive support improve functional performance including muscle strength, jumping, and dynamic balance, in a comparison with other knee braces. It was hypothesized that wearing hinged knee braces with assistive support would enhance the functional performance resulting from an increase in knee joint torque.

Methods

Participants

A total of 28 healthy participants with no exercise habits and brace use were recruited for the study (13 men, 15 women; age: 21.5 ± 0.6 years; height: 164.3 ± 8.2 cm; weight: 56.7 ± 8.6 kg). Those with orthopedic disorders, limited range of joint motion, pain, or severe dysfunction such as sudden knee buckling during running, climbing down stairs, and landing movements were excluded. This study was approved by the Research Ethics Committee of Seijoh University (16 PT06). The participants provided informed consent after receiving an explanation of the content of the study using printed materials.

Knee braces and conditions

The dominant leg of participants was determined based on the question "Which foot do you use to kick the ball?" The non-dominant leg was defined as the "supporting leg", on which the knee braces were placed. Each participant performed tasks under the following conditions: 1) without a knee brace (no brace), 2) wearing a knee sleeve without struts (ZAMST EK-1, Nippon Sigmax Co., Ltd, Japan), 3) wearing a hinged knee brace (Geltex Light Sports, Nippon Sigmax Co., Ltd, Japan), 4) wearing a knee brace with extension support (KBE), and 5) wearing a knee brace with flexion support (KBF) (Fig. 1). Of these, the hinged knee brace, KBE, and KBF were produced by the staff of the Matsumoto prosthetics and orthotics manufacturing company limited. The KBE and KBF were provided by equipping the custom-made hinged knee braces with rubber tubes (Fig. 1D and E). Rubber tubes that produced an elastic force of 2 kg with a length of 21 cm were used. The KBF assisted with production of knee flexion of 1.29, 0.54, and 0 Nm, at 0, 15, and from 30 to 90° of knee flexion, respectively. Further, the KBE assisted with production of knee extension of 2.48, 3.67, 4.53, 4.64, 4.64, 4.10, and 3.24 Nm, at 0, 15, 30, 45, 60, 75, and 90° of knee flexion, respectively. Measurements for functional performance were performed for 5 days, and a different type of brace and type of assessment were randomly assigned for each day. Further, functional performance tests were randomly provided for each participant.

Functional performance

Maximal isokinetic muscle strength in knee extension and flexion

Maximal isokinetic muscle strength was measured using an isokinetic dynamometer (Isoforce GT-360, OG GIKEN Co., Ltd, Japan). The participants were seated with the hips in 70° flexion, and restraint straps were placed at the waist and distal femur of the limb, thereby minimizing compensatory movement. The axis of the dynamometer was aligned to the lateral femoral epicondyle at 90° knee flexion, and the force arm cuff was fixed 2 cm above the medial malleolus. At the signal to start, the participants were asked to perform isokinetic flexion and extension of the knees at angular

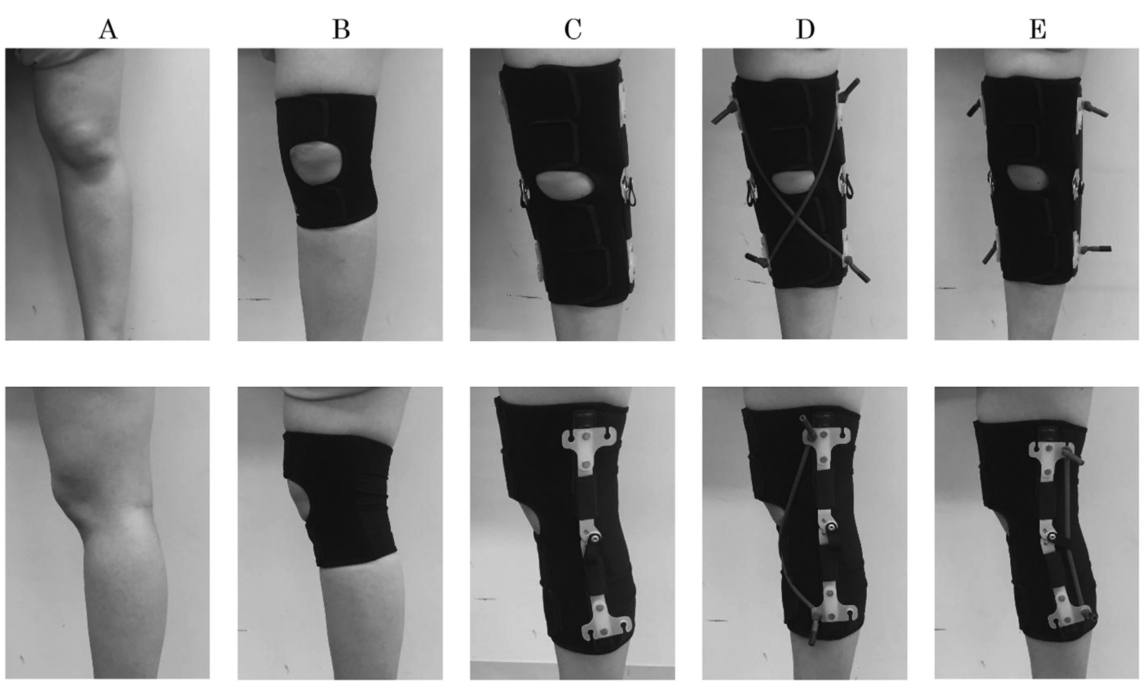

Fig. 1. The knee brace conditions used in this study. The five conditions are shown in the upper column as an anterior view and in the lower column as a lateral view: (A) no brace, (B) knee sleeve, (C) hinged knee brace without support, (D) knee brace with extension support (KBE), (E) knee brace with flexion support (KBF). KBE and KBF were provided by equipping the custom-made hinged knee braces with rubber tubes.

velocities of 120°/s at a minimum of three times with the joint angle in a range of 0°–90°. Verbal encouragement was provided to promote maximal effort in the participants. The maximum values were included in the data analysis. Maximum isokinetic strength was normalized against body weight.

Single-leg jumping height and distance

Single-leg jumping height was measured using a vertical jump measuring device (JUMP-MD, Takei Scientific Instruments Co., Ltd., Japan). No restrictions were imposed with regard to preparatory motions and elements of posture such as knee flexion angle and upper limb swing.

To measure single-leg jumping distance, the participants were asked to perform a horizontal jump in a forward direction.[9,17] They were instructed to land on a single leg with hands crossed behind their backs. These data were normalized to the participant's height. Both tests were conducted three times, and the mean values were included in the data analysis.

Single leg reach test

This test is based on the star excursion balance test.[18] The participants were asked to stand on one leg on a 2-m line drawn on the floor. They were then instructed to reach as far as possible in the anterior and posterior directions along the line using the other leg without touching the floor. Both anterior and posterior reach distances were measured three times. Reach distance was normalized to the distance from the greater trochanter to the lateral malleolus. The mean values of anterior and posterior reach were included in the data analysis.

Dynamic balance test

Dynamic balance test was assessed using the Biodex Balance System ver. 1.32 (Biodex Medical Systems Co., Ltd., USA). During the assessment, the participants stood on the platform of the device for 20 s on one leg with a slightly flexed knee (stability test). The degree of platform instability was set to increase from "8" (most stable) to "1" (most unstable). The participants were instructed to stand so that their center of gravity matched the center of the platform as much as possible, and three measurements were taken (Fig. 2).[19] The mean values of the overall stability indices automatically derived from 3 measurements were then included in the data analysis. The overall stability index represented the standard deviation of the platform displacement away from the horizontal plane.[20] Therefore, a high value for stability index indicated that a lot of movements during a test occurred in a static position.

Statistical analysis

The normality of all distributions was confirmed using the Shapiro–Wilk test. The inter-day test-retest reproducibility for functional performance between the two separate days and the average inter-day reproducibility at the 5 brace conditions were estimated using intra-class correlation coefficients (ICCs). One-way repeated measures analysis of variance (ANOVA) tests were used to compare brace conditions for each functional performance test. Significant main effects were further analyzed by using Tukey's test, which identified the significant difference test for each of the conditions. When a significant change in KBF or KBE was found for multiple comparison by any functional performance, the Pearson correlation coefficient was used to ascertain whether a change from the no brace condition in each condition was influenced by the change of knee isokinetic torque. A p value of <0.05 was considered to be statistically significant.

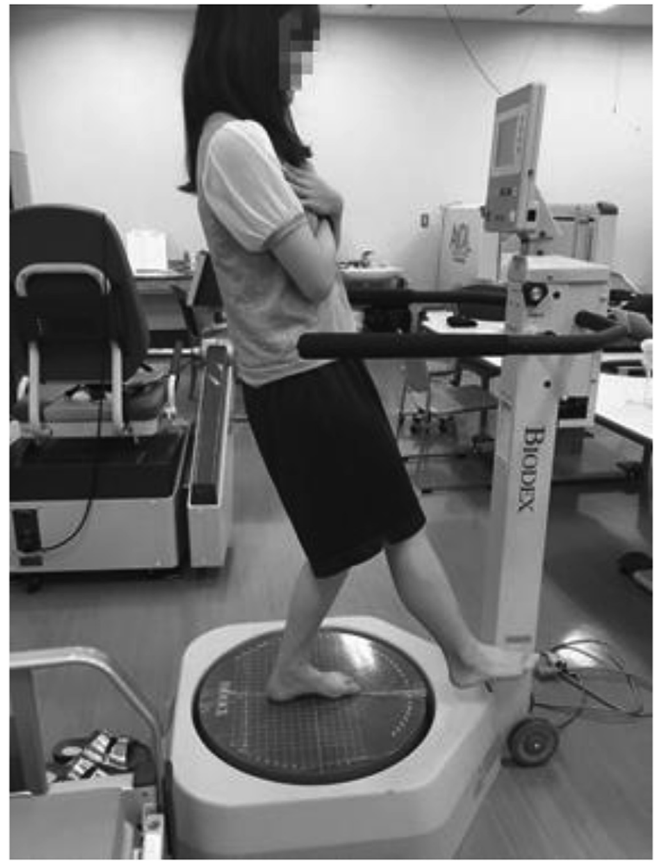

Fig. 2. The measurements posture in dynamic balance test using the BIODEX Balance System.

Results

The ICCs (95% confidence interval minimum to maximum) for functional performance were as follows: 0.80 (0.69–0.89) and 0.77 (0.64–0.87) for the maximal isokinetic muscle strength in knee flexion and extension, respectively, 0.89 (0.83–0.94) and 0.89 (0.83–0.94) for the single-leg jumping height and distance, respectively, 0.71 (0.57–0.83) and 0.82 (0.72–0.90) for the single leg anterior and posterior reach, respectively, and 0.55 (0.38–0.72) for the dynamic balance test. These ICCs indicated substantial to almost perfect reproducibility in nearly all functional performance tests, except for the dynamic balance test. The average inter-day reproducibility of the maximal isokinetic muscle strength in knee flexion, knee extension, single-leg jumping height, distance, single-leg anterior reach, posterior reach, and the dynamic balance test were 0.95, 0.94, 0.98, 0.98, 0.92, 0.96, and 0.86, respectively.

Significant main effects were observed for maximum isokinetic muscle strength during knee flexion ($F_{(4, 108)} = 3.10$, $p = 0.018$, effect size $\eta^2 = 0.02$) and single leg anterior reach distance ($F_{(4, 108)} = 3.45$, $p = 0.011$, effect size $\eta^2 = 0.03$). However, no differences were observed for maximum isokinetic muscle strength during knee extension, jumping height, distance, posterior reach on a single leg, and dynamic balance. The results of multiple comparisons for functional performance are shown in Table 1. The maximum isokinetic muscle strength during knee flexion, and the values obtained when wearing the KBF, were significantly higher than those with KBE ($p = 0.008$). The KBE had significantly greater values in single leg anterior reach distance ($p = 0.020$) when compared to the no brace condition.

Table 1
Functional performance results under study conditions.

	No brace	Knee sleeve	Hinged Knee brace	KBE	KBF
Flexion strength (Nm/kg)	1.09 ± 0.28	1.10 ± 0.25	1.10 ± 0.22	1.06 ± 0.23	1.16 ± 0.26*
Extension strength (Nm/kg)	2.27 ± 0.48	2.30 ± 0.49	2.34 ± 0.55	2.40 ± 0.49	2.30 ± 0.51
SL jumping height (%BH)	18.1 ± 4.2	18.9 ± 4.3	18.7 ± 4.7	19.0 ± 4.1	18.7 ± 4.6
SL jumping distance (%BH)	73.8 ± 14.0	75.5 ± 15.0	73.3 ± 14.9	75.6 ± 15.0	75.1 ± 14.8
SL anterior reach (%TMD)	97.2 ± 11.7	98.8 ± 12.9	98.6 ± 10.6	102.5 ± 11.9†	101.7 ± 11.7
SL posterior reach (%TMD)	116.7 ± 13.8	114.7 ± 12.5	114.5 ± 14.8	113.6 ± 13.7	115.1 ± 14.3
Stability index	4.40 ± 1.44	4.48 ± 1.68	4.24 ± 1.27	4.13 ± 1.71	4.38 ± 1.39

KBE: knee brace with extension support, KBF: knee brace with flexion support, SL: single-leg, BH: body height, TMD: trochanter-malleolus distance.
*: Significant differences in comparison with the KBE condition ($p < 0.05$)
†: Significant differences in comparison with the no brace condition ($p < 0.05$)
Values are mean ± standard deviation.

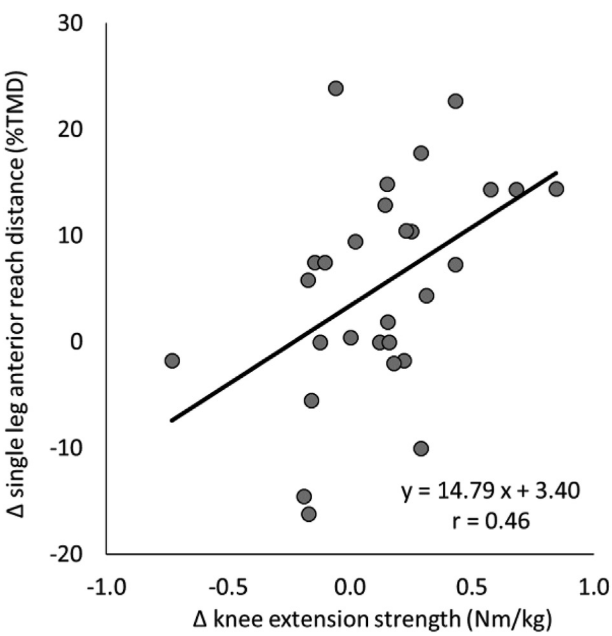

Fig. 3. Relationship between the relative changes of the knee extension torque and the anterior leg reach distance. The Δ indicates the difference in performance between KBE and the no-brace conditions.

There was a significant relationship between the improvement in the single leg anterior reach distance with KBE and the changes in isokinetic knee extension with KBE compared to the no brace condition ($r = 0.46$, $p = 0.013$, effect size $f^2 = 0.27$) (Fig. 3).

Discussion

In the present study, we investigated whether custom-made hinged knee braces can facilitate knee extensor and flexor strength and influence functional performance, as compared with other knee braces. The benefit of hinged knee braces with extension support was observed only in the anterior reach on a single leg, while no significant difference was seen in the other functional performance assessments, including jumping on a single leg, posterior reach, and dynamic balance test. In addition, the use of KBE and KBF did not increase maximal isokinetic muscle strength during knee extension and flexion compared to the no brace condition. However, the improvement in single-leg anterior reach with KBE use was related to the change in the knee extension joint torque with KBE compared to that in the no brace condition. It was interesting that minimal support improved balance function during single leg stance in the healthy knee.

The benefit of the hinged knee brace with extension support was observed only in the anterior reach on a single leg. The knee extensors are more active than the flexors during the anterior reach during a star excursion balance test.[21] Therefore, hinged knee braces with extension support increases the anterior reach distance by compensating for the activity of the extensor muscles used to maintain posture. Our brace was thought to be useful in those with weak knee extension strength during the one-legged balance because there was an association between the changes in knee extension torque with KBE use and performance improvement of the anterior reach on a single leg. Another likely explanation is that the utility of the rubber tube (i.e., placement of the rubber tube under the patellar) specific to the KBE is believed to have played a positive role in increasing cutaneous stimulation by tightening the skin when participants flexed the knee joint during the anterior reach. Studies have suggested that wearing a knee brace enhances single leg balance, which is likely accomplished by cutaneous stimulation.[1,3] Indeed, wearing a soft brace with no hinge significantly improves the torsional control of the knee in the coronal plane during eccentric step descent.[22] However, in this study, the posterior reach may have been limited because the pressure applied by the braces limited the knee flexion angle in the leg serving as the base of support during the single leg reach. This is supported by a report[23] that knee bracing (which limits knee movement) reduced the posterolateral reach distance during the star excursion balance test, whereas kinesiotaping (which does not limit knee movement) increased it.

Greater muscle strength during knee flexion was exhibited with the KBF than in the KBE condition. This suggests that flexion support provided by the knee braces marginally compensated for knee flexion strength whereas this was prevented by extension support. Conversely, this benefit was not observed with KBE during the maximal isokinetic muscle strength test in knee extension. The mean knee extension and flexion strength were 2.3 Nm/kg and 1.1 Nm/kg under no brace conditions, respectively. It was thought that the knee extension torque did not change because the elastic force of a rubber tube used for the KBE was small; however, it improves knee flexure torque.

Jumping performance on a single leg was not changed with the use of knee braces regardless of the presence or absence of assistive rubber tubing. During the assessment of knee extensors, muscle strength remained the same even when knee braces were used. Hence, it is unlikely that a change in knee extensor strength affected jumping performance. One factor that affects the height of a vertical jump is the knee flexion angle during the preparatory motion.[24,25] The use of braces may have altered the flexion angles, due to pressure applied around the knee. However, this is speculative, because we did not measure knee flexion angles during the jump. No changes in dynamic balance were observed under the assessment conditions. The ability to maintain balance during the single leg stance was affected by shank muscle activation more than by femoral muscle activation.[26,27] Furthermore, it is thought that the knee flexors were more frequently utilized for maintaining balance during single leg stance on an unstable base of support than on a firm surface.[28] Since almost all participants were able to maintain a standing posture on a single leg during the assessment of dynamic balance, they may have used the hip strategy and/or ankle strategy for posture control, because the knees were not actively involved in posture control, regardless of whether the knee brace was used.

The study has some limitations which need to be considered. An advantage of the custom-made hinged knee braces is the ability to choose the elastic force based on the participant's level of knee muscular strength; however, only one kind of rubber tube was used in this study. Hence, the extent to which a difference in individual muscular strength affects functional performance improvements obtained from brace support based on elastic force was not clarified. The analysis in this study only included the maximum values of muscle strength, and a continuous torque curve was not derived. Since the assistive rubber tubing tends to change its elastic force depending on the flexion angle of the knee, it may have slightly influenced the strength of muscle contraction, depending on the joint angle. A functional assessment on the neural recruitment pattern confirmed by surface electromyography would have further validated the results of this study. The benefit of hinged knee braces with flexion and extension support should be examined in those with instability during motion and other exercise types, particularly for gait movements that are continuously affected by knee joint function.

Conclusion

In this study of participants with healthy knees, the advantage of knee braces with extension support over other braces was limited to certain balancing motions such as the anterior reach on a single leg. There was a significant correlation between improvement of the single leg anterior reach with KBE and the rate of change of knee extension torque, suggesting that using knee braces with extension support can enhance performance during specific dynamic balance activities in individuals who benefit from improved knee extension torque.

Conflicts of interest

The authors declare no conflicts of interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jesf.2018.08.002.

References

1. Birmingham TB, Kramer JF, Kirkley A, et al. Knee bracing after ACL reconstruction: effects on postural control and proprioception. *Med Sci Sports Exerc*. 2001;33:1253–1258.
2. Baltaci G, Aktas G, Camci E, et al. The effect of prophylactic knee bracing on performance: balance, proprioception, coordination, and muscular power. *Knee Surg Sports Traumatol Arthrosc*. 2011;19:1722–1728.
3. Wu GK, Ng GY, Mak AF. Effects of knee bracing on the sensorimotor function of subjects with anterior cruciate ligament reconstruction. *Am J Sports Med*. 2001;29:641–645.
4. Sugimoto D, LeBlanc JC, Wooley SE, et al. The effectiveness of a functional knee brace on joint-position sense in anterior cruciate ligament-reconstructed individuals. *J Sport Rehabil*. 2016;25:190–194.
5. Pierrat B, Oullion R, Molimard J, et al. Characterisation of in-vivo mechanical action of knee braces regarding their anti-drawer effect. *Knee*. 2015;22:80–87.
6. Borsa PA, Lephart SM, Fu FH. Muscular and functional performance characteristics of individuals wearing prophylactic knee braces. *J Athl Train*. 1993;28:336–344.
7. Kramer JF, Dubowitz T, Fowler P, et al. Functional knee braces and dynamic performance: a review. *Clin J Sport Med*. 1997;7:32–39.
8. Coombs R, Garbutt G. Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. *J Sports Sci Med*. 2002;1:56–62.
9. Ageberg E, Roos HP, Silbernagel KG, et al. Knee extension and flexion muscle power after anterior cruciate ligament reconstruction with patellar tendon graft or hamstring tendons graft: a cross-sectional comparison 3 years post surgery. *Knee Surg Sports Traumatol Arthrosc*. 2009;17:162–169.
10. Engelen-van Melick N, van Cingel RE, Tijssen MP, et al. Assessment of functional performance after anterior cruciate ligament reconstruction: a systematic review of measurement procedures. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:869–879.
11. Abrams GD, Harris JD, Gupta AK, et al. Functional performance testing after anterior cruciate ligament reconstruction: a systematic review. *Orthop J Sport Med*. 2014;2, 2325967113518305.
12. Almangoush A, Herrington L. Functional performance testing and patient reported outcomes following ACL reconstruction: a systematic scoping review. *Int Sch Res Not*. 2014;2014:1–14.
13. Ota S, Kanai A, Torii Y, et al. Effects of a custom-made hinged knee brace with knee flexion support for patients with knee osteoarthritis:a preliminary study. *Nagoya J Med Sci*. 2015;77:95–101.
14. Barrett DS, Cobb AG, Bentley G. Joint proprioception in normal, osteoarthritic and replaced knees. *J Bone Joint Surg Br*. 1991;73:53–56.
15. Birmingham TB, Kramer JF, Kirkley A, et al. Knee bracing for medial compartment osteoarthritis: effects on proprioception and postural control. *Rheumatology*. 2001;40:285–289.
16. Osternig LR, Robertson RN. Effects of prophylactic knee bracing on lower extremity joint position and muscle activation during running. *Am J Sports Med*. 1993;21:733–737.
17. Ageberg E, Thomeé R, Neeter C, et al. Muscle strength and functional performance in patients with anterior cruciate ligament injury treated with training and surgical reconstruction or training only: a two to five-year followup. *Arthritis Rheum*. 2008;59:1773–1779.
18. Kinzey SJ, Armstrong CW. The reliability of the star-excursion test in assessing dynamic balance. *J Orthop Sports Phys Ther*. 1998;27:356–360.
19. Lee D-H, Lee J-H, Jeong H-J, et al. Lack of correlation between dynamic balance and hamstring-to-quadriceps ratio in patients with chronic anterior cruciate ligament tears. *Knee Surg Relat Res*. 2015;27:101–107.
20. Arnold BL, Schmitz RJ. Examination of balance measures produced by the biodex stability system. *J Athl Train*. 1998;33:323–327.
21. Earl JE, Hertel J. Lower-extremity muscle activation during the star excursion balance tests. *J Sport Rehabil*. 2001;10:93–104.
22. Selfe J, Richards J, Thewlis D, et al. The biomechanics of step descent under different treatment modalities used in patellofemoral pain. *Gait Posture*. 2008;27:258–263.
23. Harput G, Ulusoy B, Ozer H, Baltaci G, et al. External supports improve knee performance in anterior cruciate ligament reconstructed individuals with higher kinesiophobia levels. *Knee*. 2016;23:807–812.
24. Bobbert MF, Gerritsen KG, Litjens MC, et al. Why is countermovement jump height greater than squat jump height? *Med Sci Sports Exerc*. 1996;28:1402–1412.
25. Moran KA, Wallace ES. Eccentric loading and range of knee joint motion effects on performance enhancement in vertical jumping. *Hum Mov Sci*. 2007;26:824–840.
26. Suponitsky Y, Verbitsky O, Peled E, et al. Effect of selective fatiguing of the shank muscles on single-leg-standing sway. *J Electromyogr Kinesiol*. 2008;18:682–689.
27. De Ridder R, Willems T, Vanrenterghem J, et al. Influence of balance surface on ankle stabilizing muscle activity in subjects with chronic ankle instability. *J Rehabil Med*. 2015;47:632–638.
28. Silva P de B, Oliveira AS, Mrachacz-Kersting N, et al. Strategies for equilibrium maintenance during single leg standing on a wobble board. *Gait Posture*. 2016;44:149–154.