

Effects of Bracing on Knee Kinematics in Athletes After Anterior Cruciate Ligament Reconstruction

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Abstract

The bracing restraint effect on subjects with anterior cruciate ligament reconstruction is controversial. Purpose: The purpose of this study was to compare the effects of bracing restraint on knee kinematics during landing of vertical jump and hop movements for athletes with chronic anterior cruciate ligament reconstruction. Seven male athletes with chronic anterior cruciate ligament reconstruction. Methods: All subjects underwent 2 selected movements (vertical jump and hop) to collect the knee kinematics data under different bracing conditions (with bracing and without bracing). A two-way analysis of variance with repeated-measures design was conducted to investigate the effects of different bracing conditions and selected movements on knee kinematics. Results: The results revealed that no significant interaction between bracing condition and selected movements. The hop movement had found significantly greater degree than vertical jump in maximal knee flexion, abduction, flexion angle at maximal knee abduction, flexion angle at maximal knee external rotation, and joint excursion. Conclusions: Wearing functional knee braces did not affect knee kinematics in selected movements for subjects with chronic anterior cruciate ligament reconstruction. The hop movement had more length in joint excursion than vertical jump, suggesting that hopping may be a more harmful movement than vertical jumping for subjects with anterior cruciate ligament reconstruction.

Keywords: Brace, Knee, Biomechanics, Vertical Jump, Hop

Introduction

According to National College Athletics Association (NCAA) injury statistics from soccer, track and field, basketball, and hockey during 2000 and 2001, the most common site of injury was the knee joint [1]. The most severe knee injuries affect the cruciate ligament. The injury rate of anterior cruciate ligament (ACL) was 0.3% to 0.38% per year in North America and Europe [2-4]. ACL injury mostly occurs during exercise. Previous studies indicated that even though ACL was reconstructed after injury, kinematics of knee joint would still be changed, including changes of tibial anterior translation and changed angles of valgus/varus and tibial internal/external rotation [5-10]. Once normal joint kinematics change, translating or rolling in joint might not be smooth, leading to painful feeling and changes of neuromuscular control.

After ACL reconstruction or in the rehabilitation process, physicians or therapists recommend that patients use knee braces to protect the injured ligament of the newly grafted ligament [11]. Birmingham investigated the prescription rate of knee braces for patients receiving ACL reconstruction; 55% of physicians prescribed knee braces for patients, and 58% of

physicians recommended that patients wear knee braces during movement at least for one year [12]. Thus, the knee brace is commonly used to protect and treat patients with knee ligament injury or reconstruction. However, the American Academy of Orthopaedic Surgeons (AAOS) believes that functional knee braces can control excessive or abnormal movements only in low-load conditions or a static state [13] and cannot protect against injuries from high-impact activities or accidents. Moreover, wearing functional brace for a long time might cause quadriceps atrophy [14]. Therefore, the necessity of wearing functional brace for patients with ACL reconstructions during high-impact activities such as jump needs further evaluation. Also, previous studies have selected a single movement for evaluation of the biomechanics of the knee joint [15-20], and the effects of different movements on knee kinematics in patients with ACL reconstruction have not been compared. Therefore, the aim of this study was to compare kinematic differences during landing of a vertical jump and a hop with and without a functional brace in athletes after receiving ACL reconstruction.

Methods

Subjects

Seven male athletes at university receiving reconstruction after ACL rupture (in one side) were recruited; mean height was 171.1 ± 8.0 cm, mean weight was 77.0 ± 9.7 kg, and mean

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Table 1: Subject anthropometry data

No.	Height (cm)	Weight (kg)	Age (years)	Sports event	Surgery method	Post-surgery (month)	LKSS ¹	TAS ²
1	186	89	20	Basketball	HG*	36	95	7
2	166	66	21	Cycle	BPBG [#]	24	88	5
3	175	75	23	Handball	BPBG	13	72	6
4	173	69	23	Handball	HG	34	86	7
5	161	80	26	Soccer	HG	25	80	9
6	168	70	34	Basketball	BPBG	48	92	4
7	169	90	38	Basketball	BPBG	7	65	4
Mean	171.1±8.0	77.0±9.7	26.4±6.9	--	--	26.7±14.0	82.7	6.8

[#]BPBG, Bone-Patella-Bone graft; *HG: Hamstring graft; ¹LKSS, Lysholm Knee Scoring Scale; ²TAS, Tegner Activity Score

age was 26.4±6.9 years. Inclusion criteria were: (1) reconstruction at least 6 months previously; (2) normal flexion and extension angle of knee; (3) no injury to the meniscus; (4) ability to jump and go up and down stairs. Exclusion criteria were muscular atrophy or joint contracture resulting from injury to the lower limb. The average postoperative time of those subjects was 26.7±14.0 months, and all had finished rehabilitation and returned to normal training and competition. Of the 7 subjects, 4 had received bone-patella-bone grafts (BPBG), and the other 3 had received hamstring grafts (HG) (Table 1). Subjects' knee function was evaluated by a senior physical therapist (C.H.Y.), and subjects were asked to fill out functional scales of the knee joint, including Lysholm Knee Scoring Scale (LKSS) and Tegner Activity Score (TAS), to understand the recovery of the knee after surgery. The subjects' average score of Lysholm Knee Scoring Scale was 82.7; the average score of Tegner Activity Score was 6.8 (Table 1). The subjects were told the detail of study procedure; all subjects provided signed informed consent. The study procedure and method were approved by the Institutional Review Board of Chung-Shan Medical University.

Instrumentation

1. Ultrasound-based 3D motion analyzer

Zebris CMS-HS, ultrasound-based 3D motion analyzer (Medizintechnik GmbH, Germany), one ultrasound measured head of Zebris and two ultrasound triplets with three active sensor markers were used in this study. Placement of sensors was decided on the basis of a preliminary study [21] and data collection was not altered by wearing a knee brace. One ultrasound head with three active sensor markers was placed on lateral thigh that below the greater trochanter of the femoral bone 10 cm and to establish the thigh coordinates, and the other was placed on lateral leg above the lateral malleolus 10 cm (Figure 1) to establish the leg coordinates. The

ultrasound-measured head of Zebris was placed on the lateral side of the leg and was 50 cm away from the leg. The absolute error of measurement of Zebris CMS-HS, ultrasound-based 3D motion analyzer was less than 1 mm.⁹ The Euler angle was



Figure 1. Photograph of subject wearing a functional knee brace, demonstrated location of sensors on the thigh and shank.

used to describe angle movement, defining Y-axis rotation as flexion/extension, X-axis rotation as abduction/adduction, and Z-axis rotation as internal rotation/external rotation to establish

local coordination system. The room temperature was set between 22°C and 24°C. The amplifier gain of sensors was 255-fold; this value was the best magnification after each sensor was automatically adjusted by instruments. The sampling frequency was 100 Hz. All values after sampling were presented by real-time on the computer and were recorded in computer hardware. The data were then managed off-line. The test-retest reliability of instruments was 0.997, and the concurrent validity was 0.998. Instruments had high reliability and validity [21].

2. Functional Knee Brace

The functional knee brace used in this study was DonJoy 4TITUDE™ functional knee brace (DJO Incorporated, U.S.A.), which is the most frequently recommended by orthopedists [22]; it is suitable for patients with anterior/posterior cruciate ligament injuries.

Test Procedure

The study design was repeated-measures comparison test, comparing the test results of landing after vertical jump and hop in athletes receiving ACL reconstruction with or without functional knee brace. The study procedures are explained below:

Step 1: Explain test procedure and write study informed consents.

Step 2: After physical therapist's evaluation and completion of the Lysholm Knee Scoring Scale and Tegner Activity Score, the therapist measured a subject's lower limb size based on the DonJoy measurement standard and then selected a knee brace of suitable size for the subject.

Step 3: Next, subjects were asked to stretch their legs and warm up for 10 minutes; they then randomly drew lots for assignment to groups wearing or not wearing a functional brace and to determine the order of two tested movements. Ultrasound sensors were placed on upper segment of the thigh and above the lateral ankle, the leaning angle of the sensors was manually adjusted to face the receiver to reduce missing data, and the instruments were calibrated by standing posture.

Step 4: The test movement in this study included vertical jump and hop. When the vertical jump was performed, a subject was asked to stand up and the therapist set a target altitude, asking the subject to try his best to jump up and reach the target. When the hop was performed, the subject was asked to stand with his hands on his waist and do subject's best to jump forward. Each movement was doing 5 repetitions. When one of 2 movements was completed, the subject was allowed to rest for 10 minutes, and then had performed another movement.

Data Reduction and Analysis

AcqKnowledge 3.5.7 (Biopac Systems, Goleta, CA) was used for data reduction. Four orders Butterworth low-pass filter was used to filter digital high-frequency missing data and the cutoff frequency was set on 6 Hz. After filtering, maximal knee flexion, maximal knee abduction, maximal knee external rotation, flexion angle at maximal knee external rotation, and flexion angle at maximal knee abduction of each movement

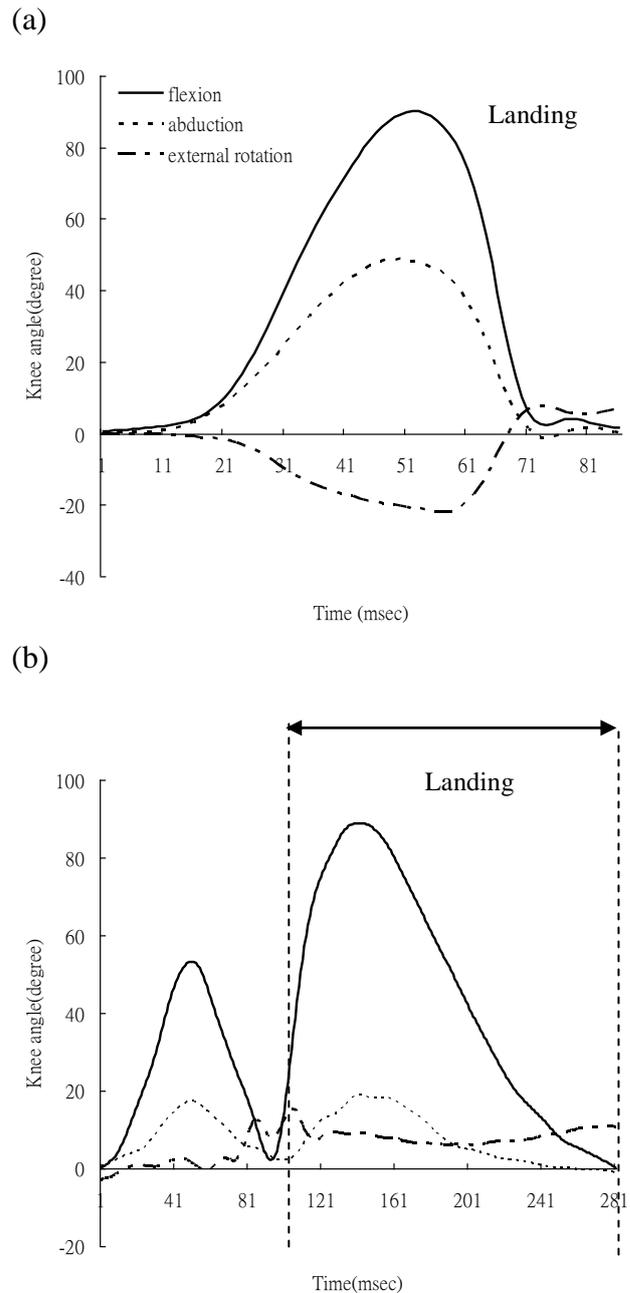


Figure 2. Changes of knee angles during vertical jump (a) and hop (b) in a subject. Data of angle changing were retrieved during landing to perform data analysis and management. The landing phase was meaning the second stage of knee angle from extension to flexion.

after landing were recorded (Figure 2). The data after filtering were used to retrieve post-landing knee abduction angle and knee external rotation angle to calculate joint excursion (JE) (Figure 2). The joint excursion was represented that the abduction angle of knee combination with rotational angle. The formula was:

$$JE = \sum \sqrt{(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2}$$

JE: Joint excursion length

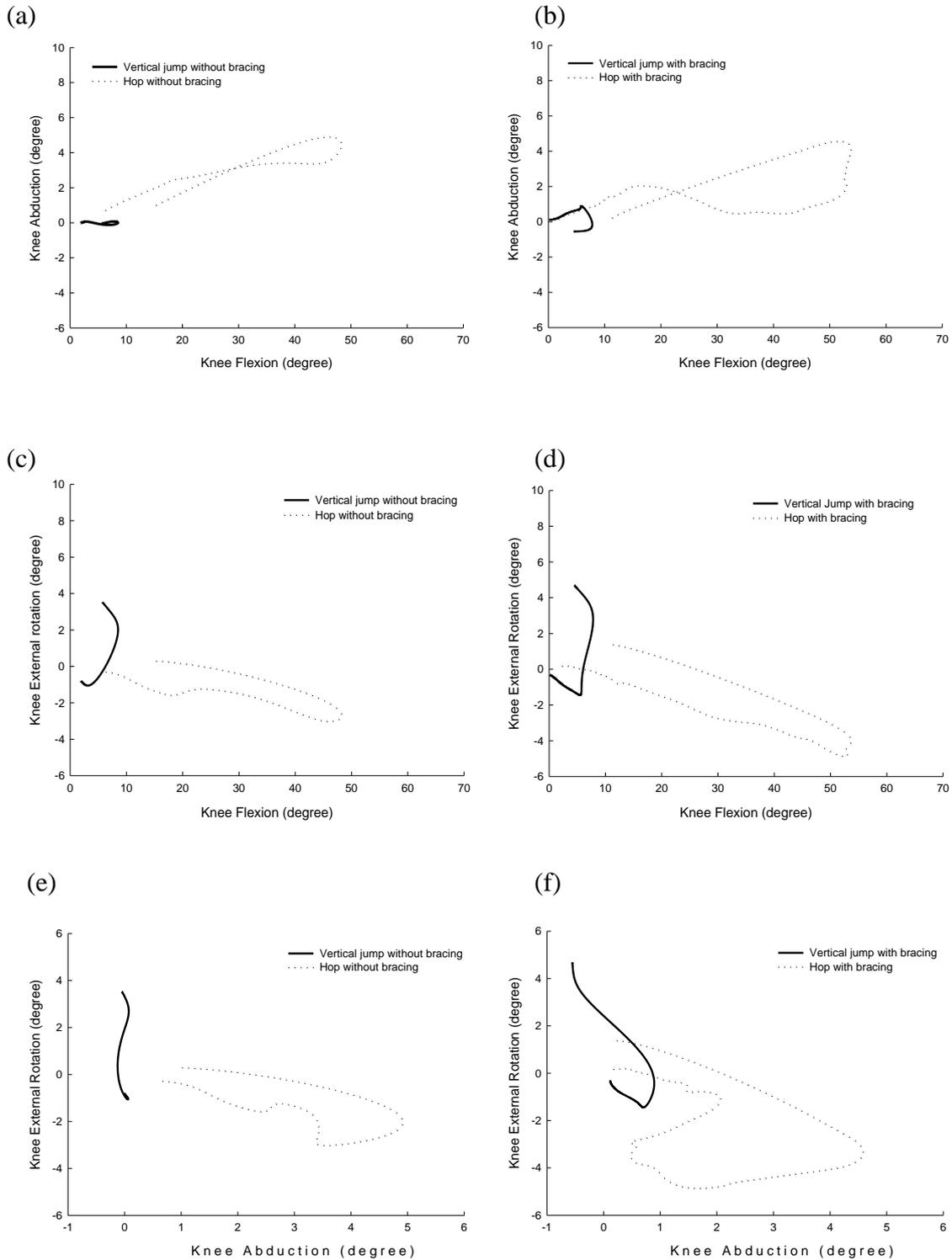


Figure 3. Relative changes of angles in knee movements. (a) Angle changes of knee flexion and knee abduction without bracing; (b) Angle changes of knee flexion and knee abduction with bracing; (c) Angle changes of knee flexion and knee external rotation without bracing; (d) Angle changes of knee flexion and external knee rotation with bracing; (e) Angle changes of knee abduction and external knee rotation without bracing; (f) Angle changes of knee abduction and external knee rotation with bracing. The continuous line represents a vertical jump, and the dotted line represents a hop.

X : Knee abduction angle
 Y : Knee external rotation angle

There were two reasons to retrieve post-landing knee abduction angle and knee external rotation angle. One reason

was that in recent years, studies have found that knee external rotation angle in patients with ACL injury and reconstruction would increase [5, 22-23], which may result in an increase of joint excursion. The other reason was that the combination movement of knee abduction and knee external rotation after landing causes anterior cruciate ligament injury and thus this combination movement is a risk zone for anterior cruciate ligament [24-26]. If the calculated joint excursion was more, it meant that the movement was more dangerous to anterior cruciate ligament and more laxity and instability that knee observed.

Table 2: The kinematic variable results of ACLR subjects with and without wearing brace during vertical jump and hop

Kinematics Variables	Vertical Jump		Hop	
	With Bracing	Without bracing	With Bracing	Without bracing
Maxflex, deg	10.05± 5.75	12.58± 7.91	75.05±22.39	71.57±24.42
Maxabd,deg	3.37± 2.25	1.59± 1.13	15.61±11.25	13.88± 9.94
MaxER, deg	8.40± 3.98	8.33± 2.11	6.52± 2.05	7.09± 2.46
Flexinabd, deg	8.23± 5.48	9.81± 7.77	78.60±15.74	74.95±21.46
FlexinER, deg	5.90± 4.56	4.78± 3.59	9.73± 7.08	14.88± 7.39
JE, rad	0.43± 0.19	0.44± 0.21	0.77± 0.36	0.72± 0.43

Table 3: P value of repeated measurement two-way ANOVA

Source	Maxflex ¹	Maxabd ²	MaxER ³	Flexinabd ⁴	FlexinER ⁵	JE ⁶
Movement	.000*	.001*	.185	.000*	.007*	.018*
Bracing	.945	.563	.828	.853	.393	.881
Movement × bracing	.662	.995	.779	.644	.190	.825

¹Maxflex: maximal knee flexion angle.

²Maxabd: maximal knee abduction angle.

³MaxER: maximal knee external rotation angle.

⁴Flexinabd: knee flexion degree at maximal knee abduction angle.

⁵FlexinER: knee flexion degree at maximal knee external rotation angle.

⁶JE: joint excursion.

* It mean $p < .05$.

SPSS 14.0 for Windows (SPSS Inc., Chicago, IL) was used for data analysis. The repeated-measures mix design two-way ANOVA was used for statistical analysis in this study. The independent variable in this study was wearing or not wearing knee brace, and the dependent variables included 6 kinematical angle factors, maximal knee flexion angle, maximal knee abduction angle, maximal knee external rotation angle, flexion angle at maximal knee abduction, flexion angle at maximal knee external rotation, and joint excursion. A significant value (α) was set on 0.05.

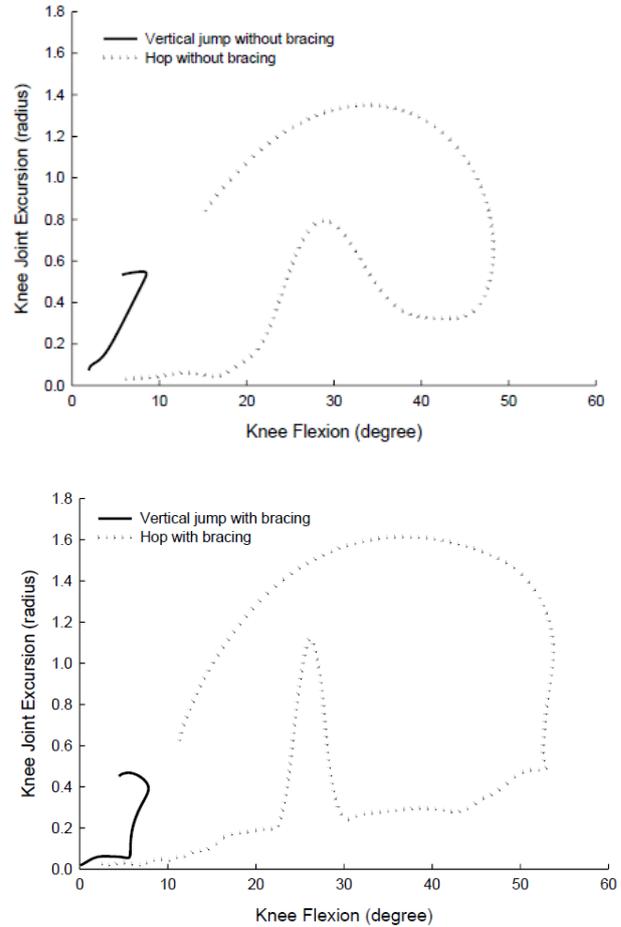


Figure 4. The graph of knee flexion angle and joint excursion. The upper graph is without bracing and lower graph is with bracing. A continuous line represents a vertical jump, and a dotted line represents a hop.

Results

The results showed that there was no significant interaction between movements of the vertical jump and hop and presence or absence of a functional knee brace; this means that the two variables were independent. Knee kinematics during landing was not influenced by wearing a functional knee brace (Table 2 and Table 3). In view of this, wearing functional knee brace might not prevent an excessive angle of the knee joint during landing. With the exception of maximal external knee rotation, other variables between the vertical jump and the hop had a significant difference. The study results showed that the hop movement had 59°–65° more knee flexion and 10°–13° more abduction than the vertical jump. The hop movement also had a greater degree in flexion angle at maximal knee abduction and at maximal knee external rotation than the vertical jump (Table 2). Furthermore, the hop movement had more length in joint excursion (0.28~0.33 radian more) than the vertical jump. Figure 3 shows changes of relative angle during landing of vertical jump and hop in all subjects with and without functional knee brace. Knee flexion angle and abduction angle of hop were significantly increased than vertical jump movement regardless of presence or absence of the knee

brace ($p < .05$). The maximal knee flexion of hop was 60.9° but that of vertical jump was only 10° . The abduction angles of hop were between 0.1° and 7.6° but those of vertical jump were between -0.6° and 1.2° (Figure 3 a-d). Regardless of vertical jump or hop, the kinematics of movements was little difference when wearing functional knee brace compare to without wearing brace, especially during the combination movement of knee external rotation and abduction. Unfortunately, the interference of functional knee brace increased angles of knee external rotation and abduction (Figure 3 e-f). Figure 4 shows knee flexion degree and joint excursion. The hop movement had more length in joint excursion than vertical jump (hop: $0.72\sim 0.77$ radian; vertical jump: $0.43\sim 0.44$ radian), which also indicated that the joint excursion was less smooth when wearing a knee brace. The flexion angles at maximal knee abduction in vertical jump and hop both occurred near the maximal flexion angles (Table 2).

Discussion

Constrain Effect of Functional Knee Brace

The functional knee brace has two major purposes: to provide knee stability for patients with ACL or other knee ligament injuries and to provide protection for those who have received ACL repair or reconstructions [27]. This study showed that in athletes with ACL reconstruction, functional knee braces did not have a significant effect in constraining movements of vertical jump and hop, especially for landing of selected movements. Therefore, functional knee brace cannot provide an external mechanical constraint for excessive movements, especially for high-impact activities. According to the results, functional knee braces may not effectively protect against injuries from high-impact activities or accidents [28]. Thus the functional knee brace does not limit excessive angles in knee joints but may interfere with physiological movements of knee joints. The protective effect of knee brace may be a result of other physiologic mechanism. Previous studies have indicated that functional knee braces were not helpful in pain reduction [29], knee range of motion [29], functional performance [30], muscle strength [12], or activity level score [31] in patients with ACL reconstructions. The braces could, however, improve neuromuscular electromyographic muscle activity and proprioception [30, 32-33]. However, few studies have compared the differences movement to impact the kinematics of knee joints with ACL reconstructions [18, 28, 34-37]. Unlike other studies, our study used two high-impact activities (vertical jump and hop) to compare difference in knee kinematics when wearing a knee brace. The study result showed that knee kinematics were not changed by wearing the knee brace and that the functional knee brace does not have sufficient constraint on movements of vertical jump and hop. Therefore these two movements constitute a risk to knee joints with ACL reconstruction.

Movement Impact on Chronic ACL Reconstruction Subjects

The study result found that the vertical jump had larger angle than the hop in knee external rotation, but the hop had

greater degree than vertical jump in knee abduction. According to the results, we thought that tibial external rotation angle of patients receiving ACL surgery could not return to normal; this may indicate that reconstructions cannot recover normal screw home mechanism in knee joints. This study found that the hop had a greater degree of knee external rotation than the vertical jump, which means that excessive tibial external rotation exists in knee joints with ACL reconstruction during performing hop movement. A hop movement could result in knee external rotation combined with abduction, increasing the risk of a second ACL injury. The findings in previous studies are inconsistent with findings in this study [38, 39], and further research is needed for clarification.

Difference of Joint Excursion between Hop and Vertical Jump A special variable in this study is joint excursion, utilizing motion geometry concept of object in mechanics. The variable of joint excursion length in this study was calculated using the knee abduction angle and the knee external rotation angle. This information is important because the torque force due to knee abduction and external rotation after landing causes ACL injury. In this posture, the ACL is twisted to its tightest state and is vulnerable to injury [24-26]. When knee abduction angle and external rotation angle is bigger, the relatively calculated excursion is longer. The longer joint excursion means that the location of knee joints in space pulls, drags, and twists the ACL, increasing the instability of the knee joint and the likelihood of ACL injury. This study demonstrated that the hop has longer joint excursion than the vertical jump. A hop movement includes vertical and horizontal components of force, and knee joints have to do quick brake stop during landing, increasing the horizontal force and increasing the joint excursion. Therefore, a hop movement is more dangerous than a vertical jump movement. Fitzgerald et al believed that the hop test could indicate the stability of knee joints in a dynamic state and could predict the risk of knee instability. Other evidence also suggests that the hop test could help predict if patients with ACL injury can participate in high-impact activities after receiving rehabilitation [40, 41].

Knee Flexion Angle at Maximal Knee Abduction and External Rotation

The flexion angle at the maximal knee abduction in vertical jump was $8.2\sim 9.8$ degrees and that in hop was $78.6\sim 75$ degrees; these were near the maximal flexion angle of each movement. The flexion angle at the maximal knee external rotation in vertical jump was $4.8\sim 5.9$ degrees, occurring in the middle segment of knee flexion; and that in hop was $9.7\sim 14.9$ degrees, occurring in the first 15 degrees of knee flexion. This indicates that early external knee rotation occurs more easily in a hop movement than in vertical jump, especially in early phase of knee from extension to flexion. However, the vertical jump had a greater degree of maximal angle of external knee rotation than the hop; this may be caused by the quick brake stop of knee joints at landing after the hop, inducing neuromuscular contraction and resulting in the adaptation of

early external knee rotation for a hop movement [42-44]. It will be worthwhile to conduct studies regarding electromyographic activities of muscles near knee joints in athletes with ACL reconstruction during landing of vertical jump and hop.

Study Limitations

In present study, knee joint angle variables were evaluated by wearing the DonJoy functional knee brace; thus the results cannot be generalized to evaluation of long-term use of knee braces and for others knee brace. The constraining effect of the knee brace and the improvement of knee kinematics were insufficient. Therefore, long-term studies should be conducted to observe the effects of long-term use of functional knee braces.

This study did not compare the difference between the affected and non-affected sides for subjects with ACL reconstruction. Also, it would not provide the normal kinematics data of subjects either wearing or not the brace. It was also the limitation for this study. However, in this study, we calculated the joint excursion as a new concept for assessment of knee kinematic. Future study would be focus on the involved and non-involved side comparison for ACL injuries or rupture to clarify the joint excursion changing.

Conclusion

The study found that, in athletes with a history of ACL reconstruction, wearing a functional knee brace did not effectively constrain movements during vertical jump and hop, especially for landing of selected movements. Moreover, knee kinematics are not changed by use of the knee brace, which means that the functional knee brace cannot provide sufficient protection during vertical jumping and hopping. The hop movement is more suitable than the vertical jump in predicting if patient with ACL injury can participate in high-impact exercise after receiving rehabilitation.

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References

- [1] NCAA. Injury Surveillance System. Washington: NCAA; 2002.
- [2] Childs, Sharon G. (2002). Pathogenesis of anterior cruciate ligament injury. *Orthop Nurs*, 21(4), 35-40.
- [3] Miyasaka, K. C., Daniel, D. M., & Stone, M. L. (1991). The incidence of knee ligament injuries in the general population. *Am. J. Knee Surg*, 4, 3-8.
- [4] Nielsen, A. B., Yde, J. (1991). Epidemiology of acute knee injuries: a prospective hospital investigation. *Journal of Trauma*, 31(12), 1644-1648.
- [5] Brandsson, S., Karlsson, J., & Sward L, et al. (2002). Kinematics and laxity of the knee joint after anterior cruciate ligament reconstruction: pre-and postoperative radiostereometric studies. *The American Journal of Sports Medicine*, 30, 361-367.
- [6] Ferber, R., Osternig, L. R., & Woollacott, M. H., et al. (2002). Gait mechanics in chronic ACL deficiency and subsequent repair. *Clinical Biomechanics*, 17(4), 274-285.
- [7] Hollman, J. H., Deusinger, R. H., & Van Dillen, L. R., et al. (2002). Knee joint movements in subjects without knee pathology and subjects with injured anterior cruciate ligaments. *Physical Therapy*, 82(10), 960-972.
- [8] Knoll, Z., Kocsis, L., & Kiss, R. M. (2004). Gait patterns before and after anterior cruciate ligament reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy*, 12, 7-14.
- [9] Freeman, M. A. R., & Pinskerova, V. (2005). The movement of the normal tibio-femoral joint. *Journal of Biomechanics*, 38(2), 197-208.
- [10] Nordin, M., Frankel, V. H. (2001). Biomechanics of the knee. In: Nordin M, Frankel VH, eds. Basic Biomechanics of the Musculoskeletal System. 3rd ed. Philadelphia, PA: Lippincott Williams & Wilkins, 176-201.
- [11] Gerber, C. (1990). Aspects of rehabilitation in the anterior cruciate ligament-deficient knee. In: Jakob RP, Staubli HU, eds. The knee and the cruciate ligaments. Berlin, Germany: Springer-Verlag, 607-612.
- [12] Birmingham, T. B., Kramer, J. F., & Kirkley, A. (2002). Effect of a functional knee brace on knee flexion and extension strength after cruciate ligament reconstruction. *Archives of Physical Medicine and Rehabilitation*, 83(10), 1472-1475.
- [13] AAOS. (1997). Position statement: The Use of Knee Braces[American Academy of Orthopaedic Surgeons web site]. Available at: <http://www.aaos.org/wordhtml/papers/position/1124.htm>
- [14] Risberg, M. A., Holm, I., & Steen, H., et al. (1999). The effect of knee bracing after anterior cruciate ligament reconstruction: a prospective, randomized study with two years' follow-up. *The American Journal of Sports Medicine*, 27(1), 76-83.
- [15] Branch, T. P., Hunter, R., & Donath, M. (1989.) Dynamic EMG analysis of anterior cruciate deficient legs with and without bracing during cutting. *The American Journal of Sports Medicine*, 17(1), 35-41.
- [16] Anderson, K., Wojtys, E. M., & Loubert, P. V., et al. (1992). A biomechanical evaluation of taping and bracing in reducing knee joint translation and rotation. *The American Journal of Sports Medicine*, 20(4), 416-421.
- [17] Devita, P., Hunter, P. B., & Skelly, W. A. (1992). Effects of a functional knee brace on the biomechanics of running. *Medicine & Science in Sports & Exercise*, 24(7), 797-807.
- [18] DeVita, P., Lassiter, T. Jr., & Hortobagyi, T., et al.

- (1998). Functional knee brace effects during walking in patients with anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine*, 26(6), 778-784.
- [19] Fleming, B. C., Renstrom, P. A., & Beynnon, B. D., et al. (2000). The influence of functional knee bracing on the anterior cruciate ligament strain biomechanics in weightbearing and nonweightbearing knees. *The American Journal of Sports Medicine*, 28(6), 815-824.
- [20] Beynnon, B. D., Fleming, B. C., & Churchill, D. L., et al. (2003). The effect of anterior cruciate ligament deficiency and functional bracing on translation of the tibia relative to the femur during nonweightbearing and weightbearing. *The American Journal of Sports Medicine*, 31(1), 99-105.
- [21] Chang, H. Y., Huang, C. H., & Wei, S. H. (2007). Test-retest reliability and validity of 3D ultrasound based motion analysis system: comparison of the goniometer and zebris system. *Journal of Biomechanics*, 40(2), S722.
- [22] Decoster, L.C., Vailas, J.C.(2003). Functional anterior cruciate ligament bracing: a survey of current brace prescription patterns. *Orthopedics*, 26(7), 701-6.
- [22] Georgoulis, A. D., Papadonikolakis, A., & Papageorgiou, C. D. (2003). Three-dimensional tibiofemoral kinematics of the anterior cruciate deficient and reconstructed knee during walking. *The American Journal of Sports Medicine*, 31(1), 75-79.
- [23] Ristanis, R., Giakas, G., & Papageorgiou, C. D., et al. (2003). The effects of anterior cruciate ligament reconstruction on tibial rotation during pivoting after descending stairs. *Knee Surgery, Sports Traumatology, Arthroscopy*, 11(6), 360-365.
- [24] Boden, B.P., Torg, J.S., Knowles, S.B., Hewett, T.E. (2009). Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. *The American Journal of Sports Medicine*, 37(2), 252-9.
- [25] Alentorn-Geli, E., Myer, G.D., Silvers, H.J., Samitier, G., Romero, D., Lázaro-Haro, C., Cugat, R. (2009). Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee Surg Sports Traumatol Arthrosc*, 17(7), 705-29.
- [26] Irrgang, J. J., Safran, M. R., & Fu, F. H. (1996). The knee: ligamentous and meniscal injuries. In: Zachazewski JE, Magee DJ, Quillen WS, eds. *Athletic Injuries and Rehabilitation*. Pennsylvania: W. B. Saunders, 623-692.
- [27] Sekiya, J. K., Wojtys, E. M. (2003). Knee braces for ligamentous instability and arthritis. In: Callaghan JJ, ed. *The Adult Knee*. Philadelphia, PA: Lippincott Williams & Wilkins, 431-453.
- [28] Sterett, W. I., Briggs, K. K., & Farley, T., et al. (2006). Effect of functional bracing on knee injury in skiers with anterior cruciate ligament reconstruction: a prospective cohort study. *The American Journal of Sports Medicine*, 34(10), 1581-1585.
- [29] Wright, R. W., Fetzter, G. B. (2007). Bracing after ACL reconstruction: a systematic review. *Clinical Orthopaedics & Related Research*, 455, 162-168.
- [30] Wu, G. K., Ng, G. Y., & Mak, A. F. (2001). Effects of knee bracing on the functional performance of patients with anterior cruciate ligament reconstruction. *Archives of Physical Medicine Rehabilitation*, 82(2), 282-285.
- [31] McDevitt, E. R., Taylor, D. C., & Miller, M. D., et al. (2004). Functional bracing after anterior cruciate ligament reconstruction: a prospective, randomized, multicenter study. *The American Journal of Sports Medicine*, 32(8), 1887-1892.
- [32] Birmingham, T. B., Kramer, J. F., & Kirkley, A., et al. (2001). Knee bracing after ACL reconstruction: effects on postural control and proprioception. *Medicine & Science in Sports & Exercise*, 33(8), 1253-1258.
- [33] Rebel, M., Paessler, H. H. (2001). The effect of knee brace on coordination and neuronal leg muscle control: an early postoperative functional study in anterior cruciate ligament reconstructed patients. *Knee Surgery, Sports Traumatology, Arthroscopy*, 9(5), 272-281.
- [34] Chang, H. Y., Huang, C. H., Wei, S. H., & Jong, Y. J. (2008). The comparison of knee kinematics in different movement for athletes with anterior cruciate ligament reconstruction. *FJPT*, 33(1), 24-33.
- [35] Lu, T. W., Lin, H. C., & Hsu, H. C. (2006). Influence of functional bracing on the kinetics of anterior cruciate ligament-injured knees during level walking. *Clinical Biomechanics*, 21(5), 517-524.
- [36] Colby, S., Francisco, A., & Yu, B., et al. (2000). Electromyographic and kinematic analysis of cutting maneuvers. Implications for anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 28(2), 234-240.
- [37] Yu, B., Herman, D., & Preston, J., et al. (2004). Immediate effects of a knee brace with a constraint to knee extension on knee kinematics and ground reaction forces in a stop-jump task. *The American Journal of Sports Medicine*, 32(5), 1136-1143.
- [38] van der Harst, J. J., Gokeler, A., & Hof, A. L. (2007). Leg kinematics and kinetics in landing from a single-leg hop for distance. A comparison between dominant and non-dominant leg. *Clinical Biomechanics*, 22(6), 674-680.
- [39] Webster, K. E., Gonzalez-Adrio, R., & Feller, J. A. (2004). Dynamic joint loading following hamstring and patellar tendon anterior cruciate ligament reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy*, 12(1), 15-21.
- [40] Fitzgerald, G. K., Axe, M. J., & Snyder-Mackler, L. (2000). A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture. *Knee Surgery, Sports Traumatology, Arthroscopy*, 8(2), 76-82.
- [41] Fitzgerald, G. K., Lephart, S. M., & Hwang, J. H., et al. (2001). Hop tests as predictors of dynamic knee stability. *J Orthop Sports Phys Ther*, 31(10), 588-597.

- [42] Ortiz, A., Olson, S., & Libby, C. L., et al. (2008). Landing mechanics between noninjured women and women with anterior cruciate ligament reconstruction during 2 jump tasks. *The American Journal of Sports Medicine*, 36(1), 149-157.
- [43] Vairo, G. L., Myers, J. B., & Sell, T. C., et al. (2008). Neuromuscular and biomechanical landing performance subsequent to ipsilateral semitendinosus and gracilis autograft anterior cruciate ligament reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy*, 16(1), 2-14.
- [44] Chappell, J. D., Creighton, R. A., & Giuliani, C., et al. (2007). Kinematics and electromyography of landing preparation in vertical stop-jump: risks for noncontact anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 35(2), 235-241.

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