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TITLE PAGE

EXTERNAL SUPPORTS IMPROVE KNEE PERFORMANCE IN ACL RECONSTRUCTED INDIVIDUALS WITH HIGHER KINESIOPHOBIA LEVELS

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1. Introduction

Anterior cruciate ligament (ACL) rupture is the most common knee injury in sports which often occurs during non-contact cutting, jumping and pivoting activities [1, 2]. ACL rupture is often treated with ACL reconstruction (ACLR) depending on the patients' expectations about the treatment, pre-injury physical activity level and desire to return to sport (RTS) [3]. Although the ACLR is performed to stabilize the knee joint to prevent further injuries, it does not guarantee patients will return to their pre-injury activity levels [4, 5].

Physical, psychological and demographical factors are shown to influence the rate of RTS after ACL surgery [6]. Making RTS decisions following ACLR depends on a group of performance based tests to detect side-to-side asymmetries and patient-reported knee function measurements [7-9]. The readiness for RTS is often assessed by a patient's ability to achieve 85% or greater on the Limb Symmetry Index (LSI) [10-12]. However, a meta-analysis demonstrated that only 64% of patients returned to sports after ACLR, whereas approximately 85% to 90% achieved successful outcomes in knee and patient-reported function assessments [4]. Therefore, psychological factors have been thought to cause the mismatch between postoperative knee function outcomes and rates of RTS [4, 13-15]. Ardern et al. [13] demonstrated an association between psychological factors and RTS rate after ACL injury. Fear of re-injury (kinesiophobia) is one of the most challenging psychological factors after ACL injuries [14, 15] and up to 24% of ACLR patients were shown not returning to sports due to kinesiophobia [14]. Kinesiophobia levels can be objectively evaluated by Tampa Scale of Kinesiophobia (TSK-17). Although TSK scores generally decrease after ACLR, higher TSK scores still exist in

RTS phases of ACLR rehabilitation and correlates to lower self-reported knee function [10, 16].

Previous studies have focused on the biomechanical effects of knee bracing after ACLR, however knee braces may also improve functional performance during tasks such as single limb balance [17, 18] and self-reported knee function in ACLR individuals [19]. Although the use of knee braces (KB) after ACLR is still a debatable issue [20, 21], ACLR individuals commonly use them in the RTS phase to improve their confidence in their affected knee [22]. It has been reported that 62.9% of surgeons recommended a brace for their patients when participating in sports after ACLR [23]. Although Goodstadt el al. [24] suggested that patients should discontinue to use bracing when they had passed RTS criteria as using knee bracing might become a hindrance to patients' performance.

Kinesiotaping (KT) applications have increased in recent years in orthopedic patients [25]. KT can be stretched up to 100% of its original length, although tension techniques can differ according to the application area [25]. There are several theories behind how KT could affect muscle activity and joint control [25, 26]. KT could be stimulating the cutaneous mechanoreceptors and thus change the recruitment of motor units [26]; KT may also stimulate the fascia and provide tension which could change the muscle activation [25]. As ACLR alters the sensory and motor components of the knee, KT application might be effective by enhancing neuromuscular control of the knee and providing functional support [27]. However, Oliveira et al. [27] found that KT had no immediate effect on enhancing balance and hop performance in ACLR individuals. As a result, there is currently limited evidence as to whether KT is effective for improving the functional performance in ACLR individuals wishing to return to pre-injury activity levels.

This study aimed to investigate the effects of a drytex hinged knee brace and kinesiotaping on functional performance and self-reported function in individuals 6 months after ACLR who desired to return to their pre-injury activity level but felt unable to do so because of kinesiophobia. It was hypothesized that such external supports would increase the functional performance and self-reported function in individuals with higher levels of kinesiophobia.

2. Methods

2.1. Study Design

We used a cross-sectional design with repeated measures in which functional performance and patient self-reported knee functions were tested with knee bracing, Kinesiotaping and no intervention, in a randomized order.

2.2. Participants

Thirty ACLR patients [Age: 25.1±7.8 yrs., BMI: 23.9±3.5 kg/m^2, Tegner Score: 6.2±1.3,] were included in this study. The ACL surgery was performed by a single orthopedic surgeon using a quadrupled semitendinosus-gracilis (single-bundle) autograft followed by a ACLR rehabilitation program. Inclusion criteria of the study were; a) isolated ACL injuries, b) unilateral arthroscopic ACLR, c) age between 17 and 45, d) pre-injury Tegner score ≥5, e) regular attendance, missing no more than 3 sessions of ACLR rehabilitation in the first three months after ACLR, f) desire to RTS but could not due to fear of re-injury (TSK-17 score ≥ 37) [28] at 6 months after ACLR.

We specified a pre-injury Tegner activity level of at least 5 to involve only physically active individuals in the study. Only the patients whose kinesiophobia level was ≥ 37 were included in this study in order to see if bracing and KT taping could help them achieve better functional outcomes and improve their confidence in the knee which had undergone ACLR. Informed consent was obtained from all individual participants included in the study, and the protocol for the study was approved by the University Institutional Review Board.

Individuals were tested under three conditions: with no intervention, with KB and with KT in a randomized order with one week interval between test conditions. The KB and KT were worn during 30 minutes before beginning the tests. The data were collected for concentric knee strength, hop distance, dynamic balance and Global Rating Scale (GRS) for evaluating self-reported knee function.

2.3. ACLR rehabilitation program

The early phases of the neuromuscular ACLR rehabilitation program started within the first week of surgery and the individuals were instructed to attend the program three days a week till 12 weeks after ACLR. The early postoperative phase of the rehabilitation emphasized limiting hemarthrosis and edema, obtaining full knee range of motion, achieving good quadriceps muscle control and contralateral limb strengthening. The progression of the rehabilitation program incorporated core, balance and strengthening exercises. The therapy sessions were individualized to the individuals's needs and the average session lasted approximately 1.5 hours. Every participant was instructed to visit the clinic for progressive neuromuscular training once in a month when they finished early phase of rehabilitation program. The progressive neuromuscular training included plyometric, running and agility training. The tests were done at 6 months post ACLR and all participants were performed each training programs before participating in this study.

2.4. Test Conditions

2.4.1. Knee brace

A prophylactic knee brace (Drytex economy hinged knee, DJO Inc., Fig. 1.), which had been found to be effective in enhancing the lower limb functional performance in healthy individuals previously [29], was chosen. This brace was designed for mild medial and lateral support of the knee during daily living activities and/or contact sports. It is constructed of nylon core and polyester lycra fabric with bilateral polycentric aluminum upright hinges with a total weight of less than 500 grams.

2.4.2. Kinesiotaping application

KT was applied to the skin over rectus femoris using the muscle facilitation technique, with a mechanical correction for patella and ligament technique for patellar tendon [25]. The participants were instructed to lie in the supine position with their knee flexed at 90 degrees. For the tape over the rectus femoris muscle, the base of the strip was applied 10 cm below the anterior superior iliac spine and fixed without tension along the line of action of the rectus femoris to the superior border of the patella. The distal end of the strip was cut into two and applied on the medial and lateral borders of the patella with 75% tension [30]. A second strip was applied over the patellar tendon with 100% tension with the knee in its most flexed position (Fig.2.). The application of the tape was performed by the same clinician experienced in the application of KT (GH).

2.5. Testing Overview

The performance tests included knee strength, hop performance and dynamic balance**.**

2.5.1. Knee strength

Concentric quadriceps and hamstring torques were measured by isokinetic dynamometer (IsoMed®2000 D&R GmbH, Germany). The participants were instructed to sit on the isokinetic dynamometer with their hips flexed at 90°. Stabilization straps were placed across the trunk, waist and the distal femur of the limb to minimize compensatory movement. The axis of the dynamometer was aligned to the lateral femoral epicondyle while the knee was flexed at 90° and the dynamometer force arm was secured 2 cm above the lateral malleolus. The distance from the dynamometer force arm to the axis of the dynamometer was recorded for each individual to allow the peak torque to be calculated.

Prior to muscle strength recordings, the participants were allowed three maximal concentric quadriceps and hamstring tests to familiarize themselves with the testing procedures and to warm-up. The participants then performed reciprocal maximal quadriceps and hamstring concentric contractions at angular velocities of 60°/s (five repetitions) and 180°/s (ten repetitions) with a one- minute rest interval between each set. Standard verbal instructions were given regarding the procedures. Quadriceps and hamstring peak torques for involved and uninvolved limbs were recorded. The quadriceps and hamstring strength indexes were calculated by the torque produced by the involved limb divided by the torque produced by the uninvolved limb, which were then expressed as a percentage.

2.5.2. Functional Performance

One leg hop distance test (OLHT) and Star Excursion Balance Test (SEBT) were used to assess the functional performance.

For the OLHT, the participants stood on one leg with toes behind a mark on the floor. They were instructed to jump as far as possible with a controlled landing. The test was performed until three successful jumps were performed for each leg. The tests was performed with the uninvolved limb first and then the involved limb. The distance was measured in centimeters and the average of the three trials was recorded.

The anterior (ANT), posteromedial (PM) and posterolateral (PL) directions of the SEBT were used to assess dynamic balance [31]. Participants were instructed to stand in the middle of the grid with tapelines extending out 100 centimeters. The angle between ANT and PM or PL directions was set at 135˚, and between PM and PL was set at 90˚. The participants were instructed to reach as far as possible along each of the three lines, make a light toe-touch on the line without shifting weight, and return to the center of the grid whilst maintaining single-leg balance. Measurements were taken from the most distal aspect of the toes. Three practice trials were given for each limb for each direction. The participants then performed three trials in the three directions for each limb. The average of the three reach distances was recorded.

LSI was calculated for each test by dividing injured limb scores by uninjured limb scores, expressed as a percentage.

2.5.3. Subjective knee scoring

GRS score was only used for involved limb after the participants finished the overall physical performance tests for each condition (no intervention, KT and KB). The patients were asked to rate their perceived level of knee performance compared to their uninvolved limb, on a scale of 100 points with the higher score showing a better outcome [32].

The International Knee Document Committee 2000 Subjective Knee Form (IKDC) and TSK-17 scores were collected once at 6 months after ACLR before all testing conditions. IKDC contains 10 items related to knee symptoms, daily and sports activities. Scores range from 0-100, higher scores indicate less disability [33]. TSK-17 includes 17 items, with scores ranging from 17 to 68 points, with higher scores indicating a greater degree of Kinesiophobia. Vlaeyen et al.[28] developed a cutoff score where TSK-17 score ≥37 is considered as a high score for patients with back pain.

2.6. Statistical Analysis

SPSS 22.0 (SPSS Inc, Chicago, IL) was used for statistical analysis. Descriptive statistics were generated for demographic data including: age, height, body mass and body mass index. In addition, pre-injury Tegner scores, knee strength, functional performance tests and patient-reported outcomes were expressed as means (M) and standard deviations (SD). A repeated measures, ANOVA, was used to determine the differences between the three conditions (no intervention, KT and KB) with a post hoc pairwise comparison tests with a Bonferroni correction. Effect sizes (ES) for the pairwise comparisons were computed using Cohen's d. ES which was interpreted as small, medium and large based on ES values of 0.2, 0.5, and 0.8 respectively. Significance level was set at $p<0.05$.

3. Results

The patients' reported outcomes are shown in Table 1 and the functional performance outcomes at all-time points are shown in Table 2.

There were no significant differences between the test conditions for uninvolved limb in SEBT. Analysis from the involved limb showed a number of differences. SEBT_PM showed a significant difference in reach distance between the conditions ($F_{(2,58)}=5.14$, $p=0.01$). The pairwise comparisons showed a significant difference between no intervention and both KT and KB, with KT and KB increasing the reach distance ($p=0.01$, ES: 0.62) and ($p=0.04$, ES: 0.47) respectively. A significant difference was also observed between the conditions in SEBT_PL reach distance ($F_{(2,58)}=4.53, p=0.01$). The pairwise comparisons showed that KB reduced SEBT_PL reach distance when compared to KT (p=0.02, ES: 0.54). There was no significant difference between the conditions in SEBT_ANT reach distance ($F_{(2,58)}$=0.27,p=0.76).

There were no significant differences between the test conditions for uninvolved limb in OLHT. Analysis from the involved limbs showed there was a significant difference between the conditions ($F_{(2,58)}$=7.04, p=0.002). The pairwise comparisons showed both KT and KB increased the hop distance compared to no intervention (KT: p=0.01, ES: 0.56 ¸KB: p=0.04, ES: 0.48) respectively.

There was a significant difference in quadriceps strength between the test conditions at 180°/s ($F_{(2,58)}$=6.52,p=0.003) and 60°/s ($F_{(2,58)}$=4.09,p=0.02). The pairwise comparisons showed that the KB increased quadriceps strength at both 180°/s (p=0.002, ES: 0.53) and 60°/s (p=0.04, ES: 0.45) compared to no intervention. No difference was observed between no intervention and KT in quadriceps strength at 180°/s or 60°/s (p=0.7) and (p=1.00) respectively. There was a significant difference between the test conditions in hamstrings strength at 180°/s ($F_{(2,58)}$=3.99,p=0.02) and 60 °/s ($F_{(2,58)}$=5.49,p=0.01). As with the quadriceps the pairwise comparisons showed that the KB increased hamstring strength compared no intervention at both 180°/s (p=0.03, ES: 0.47) and 60°/s (p=0.04, ES: 0.47). No difference was observed between no intervention and KT in hamstrings strength at 180°/s (p=0.85) and 60°/s (p=0.84).

The GRS score was found to be significantly different between the different conditions ($F_{(2,58)}$=45.19,p<0.001). The pairwise comparisons showed that individuals reported better knee function with KB when compared to no intervention and KT (p<0.001, ES: 1.64) and (p=0.03, ES: 0.49) respectively, and they also reported better knee function with KT compared to no intervention (p<0.001, ES: 1.68).

4. Discussion

The main objective of this study was to investigate the effects of a prophylactic knee brace and the application of kinesiotaping on functional performance in individuals 6 months after Anterior Cruciate Ligament reconstruction who desired to return to their pre-injury activity level, but could not due to higher levels of kinesiophobia. We observed that both KB and KT improved the balance and hop performance, and also the patient-reported knee function but only KB was found to increase the quadriceps and hamstring peak torques. Therefore, our findings supported the hypothesis that external supports improved the functional performance in ACLR individuals with higher kinesiophobia levels.

Although the participants of this study almost passed the return to sport criteria at 6 months after surgery, their lower self-reported knee function levels and higher kinesiophobia scores supported that psychological recovery and physical recovery did not occur simultaneously [4]. Hartigan et al. [16] demonstrated that large decreases in kinesiophobia levels scores were observed from pre-surgery to 6 months after surgery, but the kinesiophobia levels were still high at 6 months when the patients are typically returning to sports. In addition, higher kinesiophobia scores were found associated with lower self-reported knee function levels and a lower return to sport rate [14, 34], but no relationship was found between kinesiophobia levels and the quadriceps strength and hop performance [35]. Therefore, the lower ratio of peak torque between the involved to uninvolved sides for quadriceps (QI) in this study might not be due to higher kinesiophobia levels. Everhart et al. [15] suggested that the ACLR individuals must be willing to overcome the kinesiophobia to return to their pre-injury level of activity and sports. Therefore, the use of bracing and taping could be an option for ACLR individuals to overcome kinesiophobia during the return to sport phase of their rehabilitation.

LSI for hamstring strength, balance and hop performance (>85%) and IKDC scores (>86.2) [10] met the RTS criteria, however the QI did not meet previously published RTS criteria [10, 12]. Thomeé et al. [36] reported only 25% of the patients had reached LSI value of ≥85% for the knee extensors at 6 months after ACLR. Although the recovery of quadriceps strength is an important outcome following ACL reconstruction and decision for RTS, quadriceps strength deficits have been found as high as 39% at 6 months after ACLR [37]. In this study, quadriceps strength deficit was around 20% and which was improved with the KB to a 12.3% deficit. Previous studies reported that knee strength outcomes did not change with KB and also some studies showed that quadriceps strength decreased with KB [22, 24, 38]. Acierno et al. [38] showed knee braces did not alter muscle activity in asymptomatic individuals and they also observed a slight decrease in their quadriceps muscle torque. However, previous studies have not focused on the individuals with higher kinesiophobia levels. In the present study, it was hypothesized that the compressive force of the brace might improve the individual’s confidence in their knee and allow the individuals to exert higher peak muscle torques. The one leg hop for distance has been shown to be one of the strongest predictive parameters for assessing RTS [39]. Although the participants passed OLHT criteria, we found that both KT and KB enhanced the LSI for OLHT. Contrary to our findings, KT and KB were shown not to improve the hop performance in healthy individuals [38, 40] and in ACLR individuals at one year after surgery [24]. We postulate that these improvements in OLHT could be mostly due to psychological supports by KT and KB which may help the participants to have greater confidence in their knee while hopping which in turn may reduce their kinesiophobia.

There is some evidence that supports KB enhancing the single limb balance [17, 18] but KT has no effect on balance in ACLR individuals [27]. Wu et al. [18] found that KB enhanced the single limb standing balance at more than 5 months after ACLR. They concluded that the mechanical hinges of the brace were not an essential component for improving the balance. The improvements could have been due to the cutaneous stimulation of the skin, which is supported by Selfe et al. [41, 42] who found significant improvements in coronal and transverse plane knee movement during step descent in normal subjects and patients with knee pain when wearing tape and a soft brace with no hinge. This current study found that both KT and KB increased SEBT_PM reach distance, but KB reduced posterolateral reach distance while KT increased it. This may be due to the KB limiting the knee flexion which might in turn decrease the posterolateral reach distance.

GRS scores of the participants without no intervention demonstrated that they were not satisfied with their knee function during the tests. Lower GRS score could also support the findings of Logerstedt et al. [10] in which higher TSK scores were correlated with worse self-reported outcomes. Reporting better knee functions with KT and KB strengthen the argument that KB and KT could give psychological support to ACLR individuals thus allowing greater confidence, strength and functional performance. In addition as the KB gave more support than KT this could explain why the participants' GRS scores were higher with KB than KT.

The main adverse effect of interventions such as bracing and taping is patients' sometimes not discontinuing to use them or becoming over-reliant on them during activities and/or sports. Before suggesting bracing and taping, patients should be informed that the use of external supports may be used to assist in overcoming kinesiophobia in the short term, however the effects of long term use are unknown and cannot be advised clinically without more evidence.

There were some limitations of the study. First, the participants of the study were mostly recreationally active individuals, and thus the external supports might not be as effective for professional athletes. Second, we only included individuals who had primary ACL reconstruction. Our results may not apply for ACLR individuals who had ACLR with meniscus and/or cartilage repair.

5. Conclusion

The prophylactic knee braces and kinesiotaping applications could be a useful option to assist ACLR individuals in overcoming kinesiophobia during return to pre-injury activity level and/or sport. When compared to kinesiotaping, knee braces appeared to be more effective at enhancing knee strength and self-reported knee function. Future studies are needed to investigate the longer term effects of such interventions to overcome kinesiophobia in ACLR individuals to determine the longevity of these effects.

Competing interests

None.

Source Funding

None declared

Fig. 1. Prophylactic knee brace

Fig.2. Kinesio taping application

Table 1

Patient reported outcomes at 6 months after ACLR, and Global Rating Scale (GRS) scores for all time points

Patient-Reported Outcomes	**IKDC**	**Lysholm**	**Tampa**	**GRS_Bare**	**GRS_KT**	**GRS_KB**
N=30, Mean±SD	87.0±13.3	94.7±5.9	40.8±3.6	67.3±10.8	78.0±10.3	83.7±12.2

Table 2

ANOVA and Pairwise Comparisons between the conditions

PERFORMANCE TESTS	**No Intervention** Mean±SD	**Kinesiotaping** Mean±SD	**Knee brace** Mean±SD	**p value**
OLHT INV (cm)	144.9±33.6	153.1±34.6*	152.8±35.0*	**0.002**
OLHT UINV (cm)	161.9±28.6	164.5±27.6	164.3±29.7	0.61
OLHT LSI (%)	88.8±11.0	91.8±10.8	91.8±10.3	0.08
SEBT_ANT INV (cm)	68.9±6.8	69.1±5.9	69.4±5.8	0.76
SEBT_ANT UINV (cm)	70.8±5.9	71.1±5.2	71.8±5.6	0.30
SEBT_ANT LSI (%)	96.7±5.3	97.4±3.4	96.7±4.3	0.65
SEBT_PM INV (cm)	91.4±9.9	94.9±8.2*	94.5±10.2*	**0.009**
SEBT_PM UINV (cm)	94.6±9.7	96.8±8.3	97.2±7.8	0.13
SEBT_PM LSI (%)	97.0±5.7	99.1±4.5	98.1±4.9	0.23
SEBT_PL INV (cm)	92.9±2.1	95.0±1.8Ɨ	91.8±1.8Ɨ	**0.01**
SEBT_PL UINV (cm)	94.1±10.0	96.1±9.8	93.7±8.6	0.16
SEBT_PL LSI (%)	99.2±5.3	99.5±4.2	98.2±4.7	0.49
H INV 180°/s (Nm/kg)	1.44±0.3	1.51±0.4	1.53±0.4*	**0.02**
H UINV 180°/s (Nm/kg)	1.48±0.3	1.53±0.3	1.15±0.3	0.34
HI 180°/s (%)	97.0±11.7	98.2±15.4	101.2±15.5	0.25
H INV 60°/s (Nm/kg)	1.74±0.4	1.70±0.3	1.82±0.5*	**0.007**
H UINV 60°/s (Nm/kg)	1.79±0.3	1.84±0.3	1.78±0.3	0.19
HI 60°/s (%)	96.9±15.5	92.3±11.6	102.1±15.5*	**<0.001**
Q INV 180°/s (Nm/kg)	1.66±0.5	1.72±0.5	1.82±0.5*	**0.003**
Q UINV 180°/s (Nm/kg)	2.04±0.3	2.12±0.4	2.08±0.3	0.19
QI 180°/s (%)	80.9±17.4	85.3±20.1	86.4±13.4	0.11
QT INV 60°/s (Nm/kg)	2.20±0.8	2.21±0.7	2.33±0.7*	**0.02**
Q UINV 60°/s (Nm/kg)	2.70±0.5	2.70±0.5	2.60±0.5	0.18
QI 60°/s (%)	78.6±16.9	80.1±14.5	87.7±17.5*	**0.001**

Abbreviations: OLHT, one leg hop test; SEBT, Star excursion balance test; ANT anterior; PM, posteromedial; PL, posterolateral; H, hamstrings; Q, quadriceps; INV, involved; UINV, uninvolved; HI and QI, ratio of Involved to uninvolved side for hamstrings and quadriceps.

* Signifcant difference (p<0.05) from Pairwise Comparison between KT or KB with no intervention.

Ɨ Signifcant difference (p<0.05) from Pairwise Comparison between KT and KB.

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