Analyse critique des ratios membre opéré/membre sain pour les tests de saut après reconstruction du ligament croisé antérieur

Gokeler, A.; Wellinga, W.; Benjaminse, A.; Lemmink, K.; Seil, R.; Zaffagnini, S.

Published in:
Revue de Chirurgie Orthopedique et Traumatologique

DOI:
10.1016/j.rcot.2017.04.007

Orthopaedics & Traumatology: Surgery & Research 103 (2017) 947–951

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com/en

Original article

A critical analysis of limb symmetry indices of hop tests in athletes after anterior cruciate ligament reconstruction: A case control study

A. Gokeler[a,*], W. Welling[a,b], A. Benjaminse[a,c], K. Lemmink[a], R. Seil[d], S. Zaffagnini[e]

[a] *Center for Human Movement Sciences, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands*
[b] *Medisch Centrum Zuid, Groningen, The Netherlands*
[c] *Hanze University Applied Science, School of Sport Studies, Groningen, The Netherlands*
[d] *Département de l'Appareil Locomoteur, Centre Hospitalier de Luxembourg, Luxembourg, Luxembourg*
[e] *Rizzoli Orthopaedic Institute, University of Bologna, Bologna, Italy*

ARTICLE INFO

Article history:
Received 25 January 2017
Accepted 27 February 2017

Keywords:
Anterior cruciate ligament
Return to sports
Hop test
Limb symmetry

ABSTRACT

Background: Hop tests are frequently used to determine return to sports (RTS) after anterior cruciate ligament reconstruction (ACLR). Given that bilateral deficits are present after ACLR, this may result in a falsely high limb symmetry index (LSI), since LSI is calculated as a ratio between the values of the limbs.
Hypothesis: Athletes after ACLR would achieve LSI > 90% for the hop test. Secondly, athletes after ACLR demonstrate decreased jump distance on the single hop for distance (SLH) and triple leg hop for distance (TLH) and decreased number of hops for the side hop (SH) for both involved and uninvolved limbs compared to normative data of sex, age and type of sports matched healthy athletes.
Materials and methods: Fifty-two patients (38 males mean age 23.9 ± 3.5 years; 14 females mean age 21.7 ± 3.5 years) who had undergone an ACLR participated in this study. Patients performed the 3 hop tests at a mean time of 7 months after ACLR. Hop distance, number of side hops and LSI were compared with normative data of 188 healthy athletes.
Results: The differences between the involved limb and the uninvolved limb were significant in all hop tests (SLH $P = 0.003$, TLH $P = 0.003$, SH $P = 0.018$). For females, only significant between limb differences were found in the SLH ($P = 0.049$). For both the SLH and the TLH, significant differences were found between the involved limb and the normative data (males; SLH $P < 0.001$, TLH $P < 0.001$; females; SLH $P < 0.001$, TLH $P = 0.006$) and between the uninvolved limb and the normative data for both males and females (males; SLH $P < 0.001$, TLH $P < 0.001$; females; SLH $P = 0.003$, TLH $P = 0.038$). For the SH, only significant differences were found between the involved limb and the normative values in males ($P = 0.033$).
Conclusion: Athletes who have undergone an ACLR demonstrate bilateral deficits on hop tests in comparison to age and sex matched normative data of healthy controls. Using the LSI may underestimate performance deficits and should therefore be analyzed with caution when used as a criterion for RTS after ACLR.
Level of evidence: III, case control study.

1. Introduction

The clearance for full return to sports (RTS) to athletes after anterior cruciate ligament reconstruction (ACLR) by physicians and rehabilitation specialists is a critical point towards the end of an extensive course of rehabilitation [12]. Unfortunately, decision making to allow a patient to RTS and unrestricted physical activity after ACLR is one of the most challenging and difficult decisions clinicians have to make [1]. In a review of the literature, 40% of studies failed to use any criteria, and only 32% of studies used time post-surgery as the sole criterion to determine when an athlete may be ready for RTS after ACLR [2]. Work presented in this paper is the result of an international collaboration between orthopaedic surgeons, sport and human movement scientists and physical therapists with the objective to reduce ACL injury rates, enhance quality of life for patients after ACL injury and surgery and decrease the incidence of osteoarthritis.

Clinicians must choose tests that are objective, reliable, and valid. With regard to ACLR, objective outcome measures include clinical and functional performance tests (FPT) and are popular

* Corresponding author.
E-mail address: a.gokeler@rug.nl (A. Gokeler).

http://dx.doi.org/10.1016/j.otsr.2017.02.015

due to their ability to quantify knee function [3,4]. The FPT were developed to simulate sport specific movements in a controlled fashion.

Hop tests are the preferred type of FPT due to utilization of the uninjured limb as a control for between limb comparisons, and as a reference against which discharge from rehabilitation and RTS may be determined [5,6]. Hop tests, like the single hop for distance (SLH), the triple hop for distance (TLH), the crossover hop for distance, and the 6-m timed hop, are FPT with extensive research supporting their reliability [3,7,8,9]. Researchers have recommended that FPT should also include an endurance hop test like the side hop (SH) [10]. It is common to calculate a limb symmetry index (LSI) calculated as hop test performance of the involved limb/hop test performance of the uninvolved limb × 100% [4,11,13]. LSI criteria > 90% are often used as cut-off scores for RTS [10,14]. However, there are some concerns regarding the use of the uninvolved limb as a reference for the involved limb. Abnormal movement patterns have been reported not only for the involved limb but also the uninvolved limb after ACL injury [15]. Additionally bilateral neuromuscular deficits haven been reported after an ACL injury [16–20].

Hence, a bilateral deficit may lead to a falsely high LSI, since LSI is calculated as a ratio between the values of the limbs. An athlete may have perfect limb symmetry and yet be underprepared to compete because both extremities are much weaker or more poorly controlled than a healthy athlete. Myers et al. recently cautioned professionals to purely rely upon the LSI for the assessment of hop test performance [21]. The study of Myers et al. provided normative values for the SLH and TLH test that were based on sex, type of sport and level of competition [21]. Gustavsson et al. have reported data on the SH [22].

The purpose of the current study was therefore to compare the results of 3 different hop tests in patients after ACLR to normative data of healthy athletes. It was our hypothesis that athletes after ACLR would achieve LSI > 90% for the hop test. Secondly however, athletes after ACLR demonstrate decreased jump distance on the SLH and TLH and decreased number of hops for the SH for both involved and uninvolved limbs compared to normative data of sex, age and type of sports matched healthy athletes.

2. Materials and methods

2.1. Subjects

Fifty-two patients who had undergone an ACLR participated in this study. There were 38 male patients (mean age 23.9 ± 3.5 years) and 14 female patients (mean age 21.7 ± 3.5 years) who participated in various level I–II sports prior to injury. Normative data from 188 healthy athletes were used as controls (Table 1). Inclusion criteria for the patients were: isolated ACLR, no associated meniscus lesion requiring repair or partial meniscectomy or cartilage lesion, normal limb alignment as well as no relevant previous surgery at any other joint of the limbs. Exclusion criteria were joint effusion, varus thrust of the knee, > 50% removal of the width of the meniscus, grade 3 rupture of the collateral ligaments, concomitant ligament injuries to the posterolateral or–medial corner, traumatic or degenerative cartilage lesions > 2 cm^2, surgical procedures or injuries to contralateral limb or any history of neurological, vestibular or visual impairment. An arthroscopic ACLR with anteromedial portal technique was performed on all patients by the same 2 surgeons. All the patients underwent a standardized early rehabilitation protocol. The patients performed the test battery on average at 7 months (range 6.7–7.4) following ACLR. The study protocol met the ethical standards required by the governing Ethics Committee and informed consent was obtained from all subjects prior to data collection.

Table 1
Demographics of patients and control group.

	ACLR group		Control group			
	Males	Females	Males		Females	
			Myers et al., 2014	Gustavsson et al., 2006	Myers et al., 2014	Gustavsson et al., 2006
Number subjects	38	14	87	9	85	6
Age (years, range)	24.0 ± 3.6 (17–30)	21.7 ± 3.5 (17–28)	19.2 ± (NR) (17–24)	29.0 ± 4.0 (NR)	19.3 ± (NR) (17–22)	26.0 ± 4.0 (NR)
Weight (kg)	67.6 ± 26.7	51.0 ± 16.4		84.0 ± 10.0 (NR)		61.0 ± 6.0 (NR)
Type graft	HT (28), PT (8), ST (2), AG (1)	HT (14)				
Time post-surgery (months)	6.7 ± 1.2	7.4 ± 1.2				
Type sports (number of subjects)	Football (32) Basketball (2) Badminton (1) Korfball (1) Fitness (2)	Football (4) Basketball (1) Handball (4) Tennis (2) Korfball (2) Hockey (1)	Football, Basketball	Football, Basketball		
Isokinetic peak torque extension 60°/s (Nm) (LSI)	Involved 235.9 ± 42.4 Uninvolved 262.5 ± 38.5 (90.0%)	Involved 161.4 ± 34.1 Uninvolved 183.1 ± 28.9 (88.0%)				
Isokinetic peak torque flexion 60°/s (Nm) (LSI)	Involved 132.3 ± 22.5 Uninvolved 138.0 ± 22.5 (96.3%)	Involved 86.4 ± 19.2 Uninvolved 95.9 ± 17.8 (90.1%)				
IKDC	85.4 ± 11.0	83.6 ± 6.1				

ACLR: anterior cruciate ligament reconstruction; control group: derived from normative data; NR: not reported; HT: hamstring tendon; PT: patellar tendon; AG: allograft; ST: synthetic tendon; LSI: limb symmetry index.

2.2. Procedure

Data from 3 unilateral lower extremity hop tests were collected that included the SLH, TLH and the SH. The SLH and TLH tests were conducted as described by Noyes et al. [11]. About 5–10 practice trials were performed as relative high number of practice trials based on previous research that indicated that hop distance increases with practice [9]. Between practice and commencement of trials, patients had a 3-minute pause. For the SH, the subjects stood on the test leg, and jumped from side-to-side between two parallel strips of tape, placed 40 cm apart on the floor. The subjects were instructed to jump as many times as possible during a period of 30 s. The number of successful jumps performed, without touching the tape, was recorded [22]. Between hop trials, patients were given a 30 s rest period. Patients performed all hop test first with the uninvolved limb and order of testing was SLH, TLH and finally SH (video in supplementary material).

For all 3 hop tests, a limb symmetry index (LSI) was calculated as the mean score for involved limb/uninvolved limb × 100%. Normative data for healthy controls (CTRL), derived from 2 studies [21,22] were used for comparison with patients after ACLR. The study of Myers et al. provided normative values for each hop test that were based on sex, type of sports and level of competition [21]. In addition, they found no clinically relevant differences between dominant and non-dominant limbs in healthy athletes nor did they find differences between athletes that played football or basketball [21]. These findings allow for between group comparisons. For the SH, data were derived from the only study available in the literature to the best of the knowledge of the authors [22].

2.3. Statistical analysis

All data were normally distributed. Paired sample *t*-tests were used to investigate the difference between the distance and number of hops of the involved limb and uninvolved limb. In addition, we compared the involved and uninvolved limbs of the ACLR group to the normative data of a large sample of healthy athletes [21,22]. A matched subject design was used to compare the patient group with a control group based on sex, age and type of sports. The normative data were presented for the dominant limb as there were no clinical relevant differences between dominant and non-dominant limbs [21]. To determine differences between limbs (involved and uninvolved) and groups (ACLR and healthy control group), a 2 × 2 ANOVA was conducted for each hop test. In addition, clinically relevant differences were determined based on the standard error of measurement (SEM) of healthy athletes for the SLH and TLH. The SEM for the SH has not been reported in the literature to the best knowledge of the authors.

3. Results

The mean LSI was 95.4% for the 3 hop tests. Eighty-three percent of the patients passed criteria set as LSI > 90% for the SLH and 86.8% respectively for the TLH. In Table 2, the LSI and the absolute differences between the involved limb and the uninvolved limb in scores on the SLH, TLH and SH of the patients after ACLR patients are presented for males and females separately. For males, the differences between the involved limb and the uninvolved limb were significant for all hop tests (SLH $P = 0.003$, TLH $P = 0.003$, SH $P = 0.018$). For females, only significant differences were found in the SLH between the involved limb and the uninvolved limb ($P = 0.049$). The differences between the involved and uninvolved limbs for the SLH and TLH were all within the SEM (4.5–7.9 cm for the SLH, 15.4–23.2 cm for the TLH) except for females in the TLH, who demonstrated a side-to-side difference of 12.7 cm.

Table 2
Mean (SD) for the 3 different hop tests in patients after ACL reconstruction.

	Males	Females
SLH		
Involved limb (cm)	156.5 ± 23.5	131.3 ± 13.7
Uninvolved limb (cm)	164.0 ± 23.09	136.0 ± 13.8
LSI (%)	95.4	96.5
P value	0.003*	0.049*
TLH		
Involved limb (cm)	506.3 ± 71.4	426.5 ± 49.2
Uninvolved limb (cm)	527.9 ± 65.6	439.2 ± 49.8
LSI (%)	95.9	97.1
P value	0.003*	0.082
SH		
Involved limb (number hops)	50.4 ± 12.6	39.6 ± 14.0
Uninvolved limb (number hops)	54.0 ± 12.5	41.9 ± 11.6
LSI (%)	93.3	94.5
P value	0.018*	0.027*

SLH: single leg hop test; TLH: triple leg hop test; SH: side hop test; LSI: limb symmetry index.
* Denotes statistical significance.

Normative data and the SEM for the SLH, TLH and SH are presented in Table 3. In Table 4, the differences between the involved limb, the uninvolved limb and the normative data are presented for the 3 hop tests separately. For both the SLH and the TLH, significant differences were found between the involved limb and the normative data (males; SLH $P < 0.001$, TLH $P < 0.001$; females; SLH $P < 0.001$, TLH $P = 0.006$) but also between the uninvolved limb and the normative data for both males and females (males; SLH $P < 0.001$, TLH $P < 0.001$; females; SLH $P = 0.003$, TLH $P = 0.038$). The differences between ACLR group and controls were also clinically relevant with shorter jump distances for the SLH (involved males 35.5 cm, females 17.6 cm; uninvolved males 28.0 cm, females 13.0 cm) and for the TLH (involved males 125.7 cm, females 43.5 cm; uninvolved males 104.1 cm, females 30.8 cm). These differences exceed the SEM for healthy athletes by far and demonstrate that patients after ACLR perform significantly less on the SLH and TLH when compared to age and sex matched athletes. For the SH, only significant difference were found between the involved limb and the normative values in males ($P = 0.033$).

4. Discussion

The main findings of the current study highlights the need for a critical appraisal of LSI scores in patients after ACLR. All of patients in the current study had a mean LSI of 95.4% for the 3 hop tests, being well over the clinical cut-off of 90% symmetry frequently used for RTS criteria [5]. Despite achieving a LSI > 90%, patients demonstrated significant and clinical relevant deficits in performance for both limbs when compared to normative data from healthy

Table 3
Normative data for the 3 different hop tests.

Hop test	Study	Subjects (*n*)	Outcome	SEM (range cm/hops)
SLH	Myers et al., 2014	172	Jump distance (cm): males 192.0 ± 20.0; females 149.0 ± 17.0	4.6–7.9
TLH			Jump distance (cm): males 632.0 ± 72.0; 470.0 ± 53.0	15.4–23.2
SH	Gustavsson et al., 2006	15	Number of hops: males 55.0 ± 6.0; females 41.0 ± 16.0	NR

Mean age years: SD; NR: not reported; range; SLH: single leg hop test; TLH: triple leg hop test; SH: side hop; SEM: standard error measurement.

Table 4
Mean differences (SD) between limbs in patients after ACL reconstruction and between patients and normative data from healthy athletes for the 3 hop tests.

	Males	Females
SLH (cm)		
Difference involved limb compared to normative data	35.5 ± 23.5	17.6 ± 13.3
P value	< 0.001*	< 0.001*
Difference uninvolved limb compared to normative data	28.0 ± 23.1	13.0 ± 12.8
P value	< 0.001*	0.003*
Difference involved limb compared to uninvolved limb	7.4 ± 14.6	4.6 ± 7.7
TLH (cm)		
Difference involved limb compared to normative data	125.7 ± 71.4	43.5 ± 49.2
P value	< 0.001*	0.006*
Difference uninvolved limb compared to normative data	104.1 ± 65.6	30.8 ± 49.8
P value	<0.001*	0.038*
Difference involved limb compared to uninvolved limb	21.7 ± 42.1	12.7 ± 24.3
SH (number hops)		
Difference involved limb compared to normative data	4.6 ± 12.6	1.4 ± 13.5
P value	0.033*	0.723
Difference uninvolved limb compared to normative data	1.0 ± 12.5	(−)0.9 ± 11.2
P value	0.625	0.770
Difference involved limb compared to uninvolved limb	3.6 ± 8.9	2.3 ± 6.5
P value	0.625	0.770

SLH: single leg hop test; TLH: triple leg hop test; SH: side hop test; negative values represents better performance patients compared to control group.
* Denotes statistical significance.

athletes. Between limb comparison revealed that the differences between the involved and uninvolved limbs for the SLH and TLH were all within the SEM except for females in the TLH who exceeded the SEM. When compared to normative data, patients after ACLR had significant and clinically relevant shorter jump distances for the SLH and for the TLH. Our results are partly in agreement with others [6,23]. Pairot de Fontenay et al. studied 13 male patients at 7.4 months after ACLR. The patients demonstrated shorter jump distance for the involved limb compared to the uninvolved limb during SLH and TLH. The jump distance was 16% shorter for the SLH and 19% shorter for the TLH in the uninvolved limb in comparison to a control group [23]. The differences we found (Table 4) are greater for within group comparison but even more pronounced when patients after ACLR were compared to healthy athletes.

A possible explanation for the decreased jump performance in patients after ACLR compared to a control group could be attributed to muscle weakness as suggested by some authors [24,25]. However, in a recent systematic review, conflicting results were found for the correlation between isokinetic strength and hop tests [26]. Not only do patients after ACLR exhibit side-to-side deficits, but the uninvolved leg after ACLR is also significantly weaker to a matched leg of a control group. The overall pattern is that the ACLR leg is weaker than the uninvolved leg, which itself is weaker than that seen in matched healthy controls. This implies that the uninvolved leg is significantly affected by the ACL injury, also questioning to use the LSI for strength as a criterion for RTS [27].

The SH assesses different qualities when compared to the SLH and TLH, and is regarded as an endurance test [22]. The patients after ACLR scored very similar number of hops for the uninvolved limb compared to normative data (54.4 ACLR versus 55.0 controls) [22]. For the SH only significant differences were found for comparison between involved limb and those of healthy control group. The SH requires increased stamina in the operative limb. This may indicate the profound effect of fatigue in the involved extremity at the 6-month time period post-ACLR [13].

Considering that patients after ACLR demonstrate performance deficits compared to controls, raises the question whether the use of the LSI is an appropriate tool to detect deficits. In total, 83% of our patients passed criteria set as LSI > 90% for the SLH and 86.8% respectively for the TLH. This is in accordance with a recent systematic review of 88 studies that included 4927 patients [13]. In the analysis, the 4 standard hop tests all averaged greater than 90% LSI at 6 to 9 months postoperatively [13]. Hence, at a period in time after ACLR when indeed most athletes are cleared for RTS [28]. The cut-off score of 90% LSI for single leg hop tests may be questioned for its sole use as a criterion for RTS after ACLR as this may mask deficits. Hegedus et al. reported that criterion validity has mixed evidence based on their review regarding the ability of the studied FPT to predict functional outcome or future injury [26].

There is a paucity of normative data in the literature. Seil and coworkers identified individual patient profiles in patients after ACLR that included age, sex, preinjury level of sports and previous ACL injury [29]. A systematic identification of patient subtypes would enhance individualized rehabilitation tailored to patient's individual tolerance, needs, goals and demands (type and level of sports). Moreover, patient profiles need to be reported in more detail to allow for scientific comparison between studies. Future outcome data should not only be presented according to sex, but also according to age, preinjury level of sports as well as previous ACL injury [29].

There are several limitations of our study that should be acknowledged. First, we used athletes from various sports. However the reported differences between different sports fall well within the standard deviations of the proposed normative values, making them clinically irrelevant. Moreover, the majority of male patients were active in football and were compared to the normative data for healthy football players [21]. The second limitation is that there is conflicting evidence regarding the construct validity, criterion validity and responsiveness of hop tests [26]. Nonetheless, the authors of the current study feel that their use is warranted as they are functional maneuvers, simple to execute and do not require specialized equipment.

5. Conclusion

The collective evidence from this study highlights that athletes who have undergone an ACLR demonstrate bilateral deficits on hop tests in comparison to age and sex matched normative data for healthy controls. Using the LSI may underestimate performance deficits and should therefore be used with caution as a criterion for RTS after ACLR.

Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.otsr.2017.02.015.

References

[1] Zaffagnini S, Grassi A, Serra M, et al. Return to sport after ACL reconstruction: how, when and why? A narrative review of current evidence. Joints 2015;3:25–30.
[2] Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. Arthroscopy 2011;27:1697–705.
[3] Clark NC. Functional performance testing following knee ligament injury. Phys Ther Sport 2001;2:91–105.

[4] Grindem H, Logerstedt D, Eitzen I, et al. Single-legged hop tests as predictors of self-reported knee function in nonoperatively treated individuals with anterior cruciate ligament injury. Am J Sports Med 2011;39:2347–54.
[5] Logerstedt D, Grindem H, Lynch A, et al. Single-legged hop tests as predictors of self-reported knee function after anterior cruciate ligament reconstruction: the Delaware-Oslo ACL cohort study. Am J Sports Med 2012;40:2348–56.
[6] Xergia SA, Pappas E, Zampeli F, et al. Asymmetries in functional hop tests, lower extremity kinematics, and isokinetic strength persist 6 to 9 months following anterior cruciate ligament reconstruction. J Orthop Sports Phys Ther 2013;43:154–62.
[7] Reid A, Birmingham TB, Stratford PW, et al. Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. Phys Ther 2007;87:337–49.
[8] Munro AG, Herrington LC. Between-session reliability of four hop tests and the agility t-test. J Strength Cond Res 2011;25:1470–7.
[9] Reinke EK, Spindler KP, Lorring D, et al. Hop tests correlate with IKDC and KOOS at minimum of 2 years after primary ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 2011;19:1806–16.
[10] Thomee R, Kaplan Y, Kvist J, et al. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 2011;19:1798–805.
[11] Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. Am J Sports Med 1991;19:513–8.
[12] Bizzini M, Hancock D, Impellizzeri F. Suggestions from the field for return to sports participation following anterior cruciate ligament reconstruction: soccer. J Orthop Sports Phys Ther 2012;42:304–12.
[13] Abrams GD, Harris JD, Gupta AK, et al. Functional performance testing after anterior cruciate ligament reconstruction: a systematic review. Orthop J Sports Med 2014;2:1.
[14] Logerstedt D, Di Stasi S, Grindem H, et al. Self-reported knee function can identify athletes who fail return-to-activity criteria up to 1 year after anterior cruciate ligament reconstruction: a Delaware-Oslo ACL cohort study. J Orthop Sports Phys Ther 2014;44:914–23.
[15] Ferber R, Osternig LR, Woollacott MH, et al. Bilateral accommodations to anterior cruciate ligament deficiency and surgery. Clin Biomech (Bristol, Avon) 2004;19:136–44.
[16] Urbach D, Nebelung W, Ropke M, et al. Bilateral dysfunction of the quadriceps muscle after unilateral cruciate ligament rupture with concomitant injury central activation deficit. Unfallchirurg 2000;103:949–55.
[17] Hiemstra LA, Webber S, MacDonald PB, et al. Contralateral limb strength deficits after anterior cruciate ligament reconstruction using a hamstring tendon graft. Clin Biomech 2007;22:543–50.
[18] Konishi YU. ACL repair might induce further abnormality of gamma loop in the intact side of the quadriceps femoris. Int J Sports Med 2011;32:292–6.
[19] Negahban H, Mazaheri M, Kingma I, et al. A systematic review of postural control during single-leg stance in patients with untreated anterior cruciate ligament injury. Knee Surg Sports Traumatol Arthrosc 2014;22:1491–504.
[20] Dingenen B, Janssens L, Claes S, et al. Lower extremity muscle activation onset times during the transition from double-leg stance to single-leg stance in anterior cruciate ligament reconstructed subjects. Clin Biomech 2016;35:116–23.
[21] Myers BA, Jenkins WL, Killian C, et al. Normative data for hop tests in high school and collegiate basketball and soccer players. Int J Sports Phys Ther 2014;9:596–603.
[22] Gustavsson A, Neeter C, Thomee P, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 2006;14:778–88.
[23] Pairot de Fontenay B, Argaud S, Blache Y, et al. Contralateral limb deficit seven months after ACL-reconstruction: an analysis of single-leg hop tests. Knee 2015;22:309–12.
[24] Logerstedt D, Lynch A, Axe MJ, et al. Symmetry restoration and functional recovery before and after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2012.
[25] Schmitt LC, Paterno MV, Hewett TE. The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. J Orthop Sports Phys Ther 2012;42:750–9.
[26] Hegedus EJ, McDonough S, Bleakley C, et al. Clinician-friendly lower extremity physical performance measures in athletes: a systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. Br J Sports Med 2015;49:642–8.
[27] Larsen JB, Farup J, Lind M, et al. Muscle strength and functional performance is markedly impaired at the recommended time point for sport return after anterior cruciate ligament reconstruction in recreational athletes. Hum Mov Sci 2015;39:73–87.
[28] Petersen W, Zantop T. Return to play following ACL reconstruction: survey among experienced arthroscopic surgeons (AGA instructors). Arch Orthop Trauma Surg 2013;133:969–77.
[29] Seil R, Mouton C, Lion A, et al. There is no such thing like a single ACL injury: profiles of ACL-injured patients. Orthop Traumatol Surg Res 2016;102:105–10.