Int J Clin Exp Med 2019;12(5):5731-5737
www.ijcem.com /ISSN:1940-5901/IJCEM0090538

Original Article

Effects of core-stability training on gait improvement in patients after anterior cruciate ligament reconstruction

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Received December 27, 2018; Accepted February 11, 2019; Epub May 15, 2019; Published May 30, 2019

Abstract: Objective: The current study aimed to investigate the effects of core-stability training on gait improvement in patients after anterior cruciate ligament (ACL) reconstruction. Methods: A total of 74 male patients with injured anterior cruciate ligaments of the unilateral knee joint were included and randomized into group A and group B, with 37 patients in each group. Patients in group A practiced regular rehabilitation exercise following anterior cruciate ligament reconstruction. Patients in group B received additional core-stability training. Kinematic characteristics of unilateral knee joints in patients were determined six months later with the use of a 3D gait analyzer. Measures included gait space parameters (cadence, stride length, and gait speed), gait time parameters (gait cycle, stance-phase and swing-phase times on the normal side and affected side), knee range of motion, and peak reaction force of joints. Knee joint function was evaluated with the use of Lysholm scores. Results: The two groups showed no significant differences in age, height, body mass index, duration of disease, smoking history, drinking history, cause of injury, and postoperative training times (all P>0.05). Compared with before treatment, cadence, stride lengths, and gait speeds of the two groups were significantly increased (P<0.05). Stride width was significantly decreased after treatment (P<0.05). After treatment, cadence, stride lengths, and gait speeds were higher in group B than in group A (all P<0.05). Stride widths in group B were shorter than in group A (P<0.05). Gait cycle, along with stance-phase and swing-phase times on the normal side and affected side, in group B were better than those in group A (all P<0.05). From the first month to the sixth month after core-stability training, the active knee flexion angles and passive knee flexion angles of patients in group B were higher than those in group A (all P<0.05). Peak reaction forces of the three joints (hip, knee, and ankle) of patients in group B were higher than those in group A (all P<0.05). Lysholm scores of group B were significantly higher than those of group A (P<0.05). Conclusion: Core-stability training enables patients undergoing anterior cruciate ligament reconstruction to have significantly better gait patterns and higher abilities of body balance and coordination, with good clinical significance.

Keywords: Core-stability training, anterior cruciate ligament reconstruction, gait improvement

Introduction

Anterior cruciate ligaments (ACL) are important structures in maintaining the stability of the knee joint. They connect the femur and the tibia to prevent the tibia from excessively shifting forward. ACL tears or complete tears are ACL injuries. The causes of ACL injury are diverse, mainly including improper sports, industrial accidents, and traffic accidents. Of these, ACL injuries caused by sports account for 34.9%. Industrial accidents account for 30.2%. Traffic accidents account for 28.6% and others account for 6.3% [1]. ACL injuries may cause dysfunction of the knee joint, induce intermittent injuries of other joint cartilages or tissues, and contribute to the retrogression of knee joint function, posing a direct effect on the daily life and motion of patients [2]. At present, ACL injuries can be cured, to some extent, with clinical treatment. However, ACL patients are prone to knee osteoarthritis. The nerve reflex function cannot be effectively restored, thereby leading to the degeneration of the knee joint and occurrence of osteoarthritis [3]. Studies have found that, although ACL reconstruction partially restores knee stability, maximum knee angles and maximum knee flexion of patients do not improve significantly [4]. Other studies have found that patients with ACL injuries undergoing normal rehabilitation training had a longer joint-recovery time. Some patients may develop muscle atrophy, osteoarthritis, and other adverse symptoms [5].

Core-stability training refers to training the strength and balance of the core muscles of the human body to effectively resist external loads exerted on the body trunk, maintain the entire spine posture, and to enhance the coordination and stability of limb mobility [6]. Some studies have found that core fatigue can cause the knee joint to be at a high-tension state, resulting in ACL damage. Core-stability training can improve core anti-fatigue ability, leading to better movement of the lower limbs [7]. The current study explored the effects of core-stability training on gait improvement in patients undergoing ACL reconstruction, aiming to propose new ideas for rehabilitation treatment.

Materials and methods

Patient data

This study was approved by the Ethics Committee of the First People's Hospital of Yunnan Province and informed consent was obtained from all patients. A total of 74 male patients treated in the First People's Hospital of Yunnan Province, from March 2017 to April 2018, were selected. Subjects were diagnosed with ACL injuries, according to the 2015 American Academy of Orthopedic Surgeons Guidelines for diagnosis and treatment of ACL injuries (all patients underwent knee MRIs, anterior drawer tests, axial shift tests, and Lachman tests for positive screening). After ACL reconstruction, patients were randomized into group A (n=37) and group B (n=37) using the random number table method. Group A practiced rehabilitation exercises after regular ACL reconstruction, while group B practiced additional core-stability training.

Inclusion criteria: (1) All patients were males, 18-40 years of age, diagnosed with ACL injury of the unilateral knee joint with the use of clinical examination and MRI; (2) Patients experienced arthroscopic diagnosis and parallel reconstruction of ipsilateral autologous hamstring tendon; and (3) Patients with complete basic clinical information.

Exclusion criteria: (1) Patients with collateral ligament injury; (2) Patients with muscle injury in the waist, upper limbs, and back; (3) Patients with ACL injuries that remained for more than 3 months; and (4) Patients with serious diseases, such as heart disease, cancer, and vital organ failure.

Exercise after ACL reconstruction

For patients in group A, routine rehabilitation training included muscle strength and endurance training of the lower limbs and standing balance training [3]. The second day after the operation, the patients could walk with double crutches. However, the affected limbs with ACL injuries were unable to support weight. When resting, the patients needed to use a brace to fix the knee joint. The knee joint was fully extended in a straight line and the patients started straight leg raising exercises. One month after the operation, the patients could perform passive extension and active flexion of the knee joint. According to patient conditions, the flexion angle was gradually increased to 120°, when the patients could perform non-weight-bearing joint flexion exercise. Patient-rehabilitation training must gradually increase the intensity of muscle exercise. Patients practiced this set of exercises 1 hour every day for 6 consecutive months. Patients in group B underwent core-stability training in addition to routine training [6], including the following: (1) Transversus abdominis and multifidus muscle contraction exercises: Patients were in the supine position to inhale deeply and to relax the abdominal muscles. They exhaled slowly to contract the abdomen as much as possible for 10 seconds, repeating 20 times; (2) Body trunk control training: Patients in the supine position extended the scapula while moving abdominal muscles and bending the knee for oblique abdominal exercises. Patients in the sitting stance moved the body forward and backward and to perform body flexion movement. Patients in the standing position moved the body trunk slantwise forward and returned to the upright position. This was repeated 20 times. Patients then moved the body trunk tilted back and returned to the upright position. This was repeated 20 times. Patients practiced this set of exercises 1 hour every day for six consecutive months.

Computer-aided 3D gait analysis system for comparison of walking parameters

Motion Analysis 3D gait analysis (purchased from Motion, USA) was used for testing. First,

Table 1. Basic data

Group	Group A (n=37)	Group B (n=37)	t/χ^2	P
Age (year)	27.6±2.4	26.5±3.1	1.707	0.092
Height (cm)	168.41±8.26	165.82±7.62	1.402	0.165
Body mass index (kg/m^2)	24.18±2.37	24.87±2.43	1.237	0.220
Duration of disease (week)	9.24±0.41	9.12±0.36	1.338	0.185
Smoking history (n, %)	23 (62.2)	21 (56.8)	0.474	0.636
Alcohol history (n, %)	15 (40.5)	17 (45.9)	0.469	0.639
Causes of injuries (n, %)			0.230	0.632
Improper sports	24 (64.9)	22 (59.5)		
Traffic accidents	13 (35.1)	15 (40.5)		
Postoperative training time (d)	3.76±0.51	3.87±0.48	0.955	0.343

the sensor that collected the motion data was respectively bound to the subject's posteromedial sacrum, anteromedial femur, the flat surface of the medial part of the tibia, and to the flat surface of the foot back. Patients walked 12 m in a straight line, under undisturbed conditions, to determine the kinematic characteristics of the unilateral knee joint, including gait space parameters (cadence, stride length, stride width, and gait speed), gait time parameters (gait cycle, stance-phase, and swing-phase time on both the normal side and affected side), knee range of motion, and peak reaction force of the joint.

Cadence refers to the number of steps taken per minute, expressed in step/min. Stride length is the distance between the center points of the two feet after one step, in the unit of cm. Stride width refers to the distance between the interior footstep line and the ipsilateral footstep line of the neighboring left and right feet within a footprint cluster, in the unit of cm. Gait speed is the average gait speed of walking, measured in cm/s. Gait cycle is the time for the same foot to heel off the ground and then heel onto the ground, in the unit of seconds. Stance-phase time on normal side is the percentage of the normal side single-foot stance time in the entire gait cycle, expressed as a percentage. Swing-phase time on normal side is the percentage of time during which the normal side limbs are in the swing phase in the gait cycle, expressed as a percentage. Stance-phase time on affected side is the percentage of the patients single-foot stance time in the gait cycle, expressed as a percentage. Swing-phase time on affected side is the proportion of time during which the patient's body is in the swing phase in the gait cycle, expressed as a percentage, Patient knee joint function was assessed using Lysholm scores [7]. Data acquisition was performed using EvaRT motion image acquisition software.

Statistical analysis

SPSS 19.0 software was employed to analyze data. Measurement data are presented as mean ± standard deviation. Comparisons between groups were processed using independent sample t-tests, while comparisons before and after treatment within groups were processed using paired t-tests. Count data are represented by number/percentage (n/%) and were processed using χ^2 tests. $P<0.05$ indicates statistically significant differences.

Results

Basic data

Differences in age, height, body mass index, duration of disease, smoking history, duration of alcohol consumption, and postoperative training times between the two groups were not statistically significant (all $P>0.05$). See **Table 1**.

Comparison of gait space parameters

Compared with before treatment, cadence, stride lengths, and gait speeds of the two groups were significantly increased (all $P<0.05$), while stride widths significantly decreased after treatment ($P<0.05$). After treatment, cadence, stride lengths, and gait speeds of group A were 41.6±4.5 times/min, 56.1±4.7 cm, and 37.4±4.3 cm/s, respectively. Cadence, stride lengths,

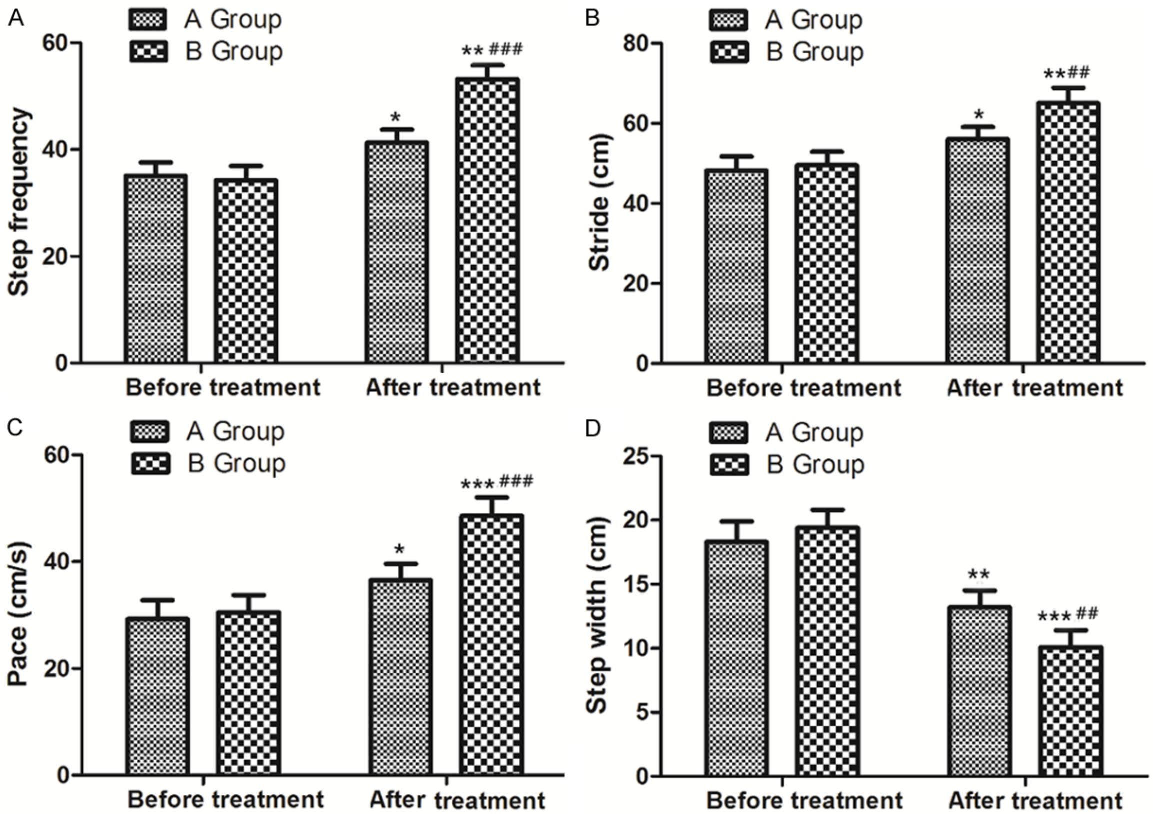

Figure 1. Comparison of gait space parameters. *P<0.05, **P<0.01, ***P<0.001, ##P<0.01, ###P<0.001.

Table 2. Comparison of gait time parameters

Group	Group A		Group B	
	Before treatment	After treatment	Before treatment	After treatment
Gait cycle (s)	1.56±0.21	1.49±0.17*	1.61±0.18	1.31±0.17*,##
Stance-phase time on affected side (%)	72.41±5.36	65.28±5.28**	71.67±5.17	59.28±5.12**,###
Stance-phase time on normal side (%)	78.62±5.07	73.95±5.16**	79.42±4.52	68.34±5.51**,###
Swing-phase time on affected side (%)	29.38±4.29	32.16±4.15*	28.27±3.76	36.09±4.52**,##
Swing-phase time on normal side (%)	18.48±3.26	25.34±3.17**	19.42±3.26	31.42±3.27**,###

Note: Compared with before treatment, *P<0.05, **P<0.01; compared with group A, ##P<0.01, ###P<0.001.

and gait speeds of group B were 52.3±4.8 times/min, 63.4±5.7 cm, and 46.5±5.2 cm/s, respectively, indicating that cadence, stride lengths, and gait speeds were higher in group B than in group A (all P<0.05). The stride width of group A was 14.6±1.6 cm, while that of group B was 11.8±2.1 cm, suggesting that the stride width of group B was significantly shorter than that of group A (P<0.05). See **Figure 1**.

Comparison of gait time parameters

After treatment, group B showed better gait cycle, stance-phase times, and swing-phase times, on the normal side and affected side, than group A (all P<0.05). See **Table 2**.

Comparison of knee range of motion

From the first month to the sixth month, active knee flexion angles and passive knee flexion angles of patients in group B were higher than those of patients in group A (all P<0.05). See **Figure 2**.

Comparison of joint peak reaction force

To avoid interference of patient body weights with the peak reaction force of joints, the ratio

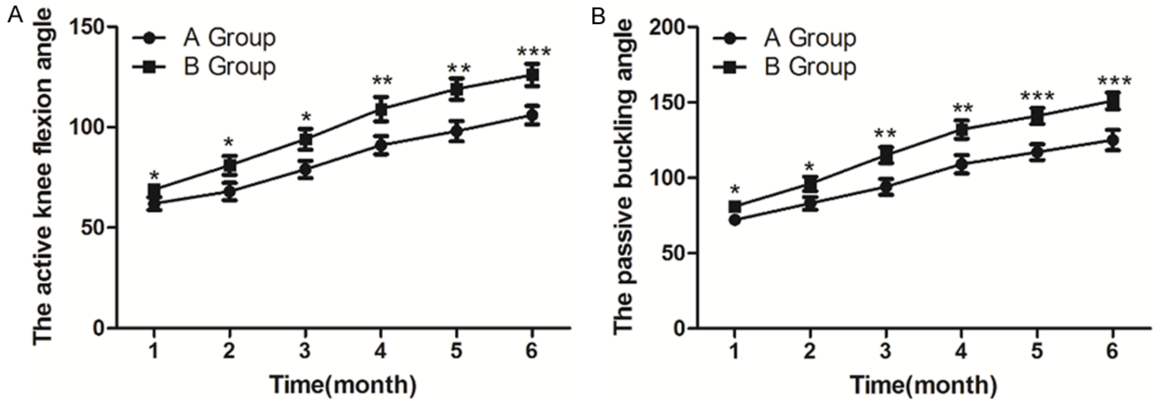

Figure 2. Comparison of knee range of motion after training. *P<0.05, **P<0.01, ***P<0.001.

Table 3. Comparison of joint peak reaction force

Group	Group A	Group B	t	P
Reaction force of hip (N/kg)	49.36±6.18	53.64±5.72	3.092	0.002
Reaction force of knee (N/kg)	46.51±8.26	51.43±7.94	2.612	0.011
Reaction force of ankle (N/kg)	64.37±6.27	73.42±5.29	6.710	<0.001

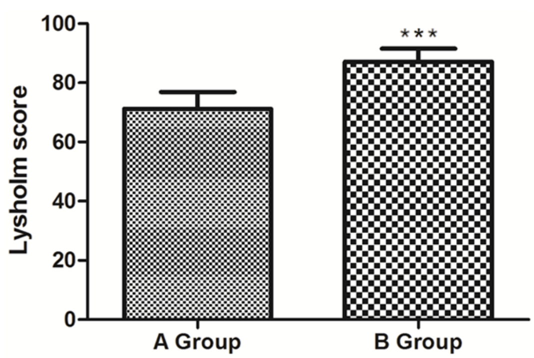

Figure 3. Comparison of Lysholm scores. Compared with group A, ***P<0.001.

of the peak reaction force to the body weight was adjusted. It was found that the peak reaction forces of the three joints (hip, knee, and ankle) in group B were all higher than those in group A (all P<0.05). See **Table 3**.

Comparison of knee joint function

Lysholm scores in group A and group B were, respectively, 72.65±5.16 and 83.46±7.41, suggesting that group B demonstrated higher Lysholm scores than group A (P<0.05). See **Figure 3**.

Discussion

ACL injuries have an adverse effect on knee joint function. However, ACL reconstruction does not fully restore the dynamic stability of the knee joint, resulting in slower recovery of exercise capacity [8, 9]. The ACL contains mechanical receptors and has a nerve reflex function. Injuries not only damage the stability of the knee joint but also impact nerve function. After reconstruction, nerve reflex function is not well restored causing the occurrence of knee joint degeneration and osteoarthritis [10, 11]. Pamukoff et al. found abnormal gait characteristics in patients with ACL injuries. After ACL reconstruction, patients treated with conventional rehabilitation showed partial recovery, but failed to return to normal levels [12]. Some studies found that core-stability training significantly improved the standing balance of patients with cerebrovascular disorder and hemiplegia, as well as improving gait characteristics [13]. Therefore, investigating core-stability training is significant in the improvement of gait after ACL reconstruction.

Chun et al. believed that core stability played an important role in regulating the movement capacity of human limbs. By increasing the strength of the trunk and hip joints to resist the stress applied to the spine, core stability could facilitate the integration and control of the forces of the proximal and distal muscles, better optimizing the body's motor function [14]. Gait speed is an important parameter for evaluation of gait and can measure the walking ability of subjects. Cadence represents the stability of walking and stride width is an indicator that measures the balance ability of the subjects, since increases in stride width means weaker stability [15, 16]. The current study showed that, after 6 months of core-stability training, group B showed higher cadence, stride lengths, and gait speeds, as well as lower stride widths, compared to group A. Present results are in line with existing research findings [17]. Some studies have found that the balance function and coordination ability of the lower limbs of patients that have experienced ACL reconstruction are not effectively restored. Core-stability training could improve gait speed, cadence, and stride length, consistent with the present study [18]. Results of this study suggest that core-stability training may contribute to the stability of the body trunk and promote the coordinated movement of limbs and muscles to enhance patient gait effects.

According to this study, the proportion of stance-phase times, on both the normal side and affected side, in group B decreases the gait cycle, while the swing-phase times on affected side shortens but increases the proportion of the gait cycle. Active knee flexion angles and passive knee flexion angles of patients in group B were higher than those of patients in group A, suggesting that core-stability training can promote the control and contraction of the ventral muscles of the body trunk and benefit the swing of affected lower limbs. Peak reaction force of the joint is an indicator assessing the strength of a subject during exercise [19]. This study found that the peak reaction forces of three joints (hip, knee, and ankle) were higher in group B than in group A, indicating that group B patients had better joint mobility. Lysholm scores are important indicators evaluating knee joint function. Higher scores indicate better knee joint ability [20]. After core-stability training, group B demonstrated significantly higher Lysholm scores than group A, suggesting that core-stability training is beneficial in enhancing knee joint function. Studies have shown that core-stability training can enhance the body's ability to stabilize under non-equilibrium conditions and reduce occurrence of sprains and falls during exercise [21, 22]. After Saccomanno et al. performed core-stability training in 17 patients with ACL injuries, dynamic gait indices in patients were improved, consistent with the current study [23].

Results of gait analysis are closely related to the hardware performance of the device and the exercise habits of subjects. However, the number of patients included in this study was small. Thus, the factors above may have caused a variance in results. Therefore, more cases are necessary to obtain more accurate gait-analysis data in further studies.

In conclusion, core-stability training can promote the improvement of gait characteristics after ACL reconstruction, as well as improve patient balance of exercise ability and coordination ability. It is, therefore, highly significant and worthy of clinical application.

Disclosure of conflict of interest

None.

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References

[1] Shamsi M, Sarrafzadeh J, Jamshidi A, Zarabi V and Pourahmadi MR. The effect of core stability and general exercise on abdominal muscle thickness in non-specific chronic low back pain using ultrasound imaging. Physiother Theory Pract 2016; 32: 277-283.

[2] Faramarzi M, Banitalebi E, Nori S, Farzin S and Taghavian Z. Effects of rhythmic aerobic exercise plus core stability training on serum omentin, chemerin and vaspin levels and insulin resistance of overweight women. J Sports Med Phys Fitness 2016; 56: 476-482.

[3] Haruyama K, Kawakami M and Otsuka T. Effect of core stability training on trunk function, standing balance, and mobility in stroke patients. Neurorehabil Neural Repair 2017; 31: 240-249.

[4] Cabanas-Valdes R, Bagur-Calafat C, Girabent-Farres M, Caballero-Gomez FM, du Port de Pontcharra-Serra H, German-Romero A and Urrutia G. Long-term follow-up of a randomized controlled trial on additional core stability exercises training for improving dynamic sitting balance and trunk control in stroke patients. Clin Rehabil 2017; 31: 1492-1499.

[5] Kim YK, Ahn JH and Yoo JD. A comparative study of clinical outcomes and second-look arthroscopic findings between remnant-preserving tibialis tendon allograft and hamstring tendon autograft in anterior cruciate ligament reconstruction: matched-pair design. Clin Orthop Surg 2017; 9: 424-431.

[6] Choi S, Kim MK, Kwon YS and Kang H. Clinical and arthroscopic outcome of single bundle anterior cruciate ligament reconstruction: comparison of remnant preservation versus conventional technique. Knee 2017; 24: 1025-1032.
[7] Taketomi S, Inui H, Tahara K, Shirakawa N, Tanaka S and Nakagawa T. Effects of initial graft tension on femoral tunnel widening after anatomic anterior cruciate ligament reconstruction using a bone-patellar tendon-bone graft. Arch Orthop Trauma Surg 2017; 137: 1285-1291.
[8] Bordes P, Laboute E, Bertolotti A, Dalmay JF, Puig P, Trouve P, Verhaegue E, Joseph PA, Dehail P and De Seze M. No beneficial effect of bracing after anterior cruciate ligament reconstruction in a cohort of 969 athletes followed in rehabilitation. Ann Phys Rehabil Med 2017; 60: 230-236.
[9] Desai N, Andernord D, Sundemo D, Alentorn-Geli E, Musahl V, Fu F, Forssblad M and Samuelsson K. Revision surgery in anterior cruciate ligament reconstruction: a cohort study of 17,682 patients from the Swedish National knee ligament register. Knee Surg Sports Traumatol Arthrosc 2017; 25: 1542-1554.
[10] Vundelinckx B, Herman B, Getgood A and Litchfield R. Surgical indications and technique for anterior cruciate ligament reconstruction combined with lateral extra-articular tenodesis or anterolateral ligament reconstruction. Clin Sports Med 2017; 36: 135-153.
[11] Pierce TP, Issa K, Festa A, Scillia AJ and McInerney VK. Pediatric anterior cruciate ligament reconstruction: a systematic review of transphyseal versus physeal-sparing techniques. Am J Sports Med 2017; 45: 488-494.
[12] Pamukoff DN, Pietrosimone BG, Ryan ED, Lee DR and Blackburn JT. Quadriceps function and hamstrings co-activation after anterior cruciate ligament reconstruction. J Athl Train 2017; 52: 422-428.
[13] Karczewska M, Madej A, Sadowska A, Mastalerz A and Urbanik C. Comparison of ground reaction forces during the basic step on the core board platform at various levels of stability. Acta Bioeng Biomech 2016; 18: 63-70.
[14] Chun JY, Seo JH, Park SH, Won YH, Kim GW, Moon SJ and Ko MH. Effects of 3-dimensional lumbar stabilization training for balance in chronic hemiplegic stroke patients: a randomized controlled trial. Ann Rehabil Med 2016; 40: 972-980.
[15] Zheng X, Xu W, Gu J, Hu Y, Cui M, Feng YE and Gao S. Effects of graft preconditioning on gamma-irradiated deep frozen tendon allografts used in anterior cruciate ligament reconstruction. Exp Ther Med 2018; 16: 1338-1342.
[16] Notarnicola A, Maccagnano G, Barletta F, Ascatigno L, Astuto L, Panella A, Tafuri S and Moretti B. Returning to sport after anterior cruciate ligament reconstruction in amateur sports men: a retrospective study. Muscles Ligaments Tendons J 2016; 6: 486-491.
[17] Pedoia V, Russell C, Randolph A, Li X and Majumdar S. Principal component analysis-T1rho voxel based relaxometry of the articular cartilage: a comparison of biochemical patterns in osteoarthritis and anterior cruciate ligament subjects. Quant Imaging Med Surg 2016; 6: 623-633.
[18] Leite ML, Cunha FA, Costa BQ, Andrade RM, Diniz Junior JH and Temponi EF. Relationship between peri-incisional dysesthesia and the vertical and oblique incisions on the hamstrings harvest in anterior cruciate ligament reconstruction. Rev Bras Ortop 2016; 51: 667-671.
[19] Dei Giudici L, Fabbrini R, Garro L, Arima S, Gigante A and Tucciarone A. Arthroscopic transphyseal anterior cruciate ligament reconstruction in adolescent athletes. J Orthop Surg (Hong Kong) 2016; 24: 307-311.
[20] Alonso B, Sobron FB, Vidal C and Vaquero J. [Pretibial pseudocyst after anterior cruciate ligament reconstruction with a biocomposite screw]. Acta Ortop Mex 2016; 30: 150-153.
[21] Zhang H, Qiu M, Zhou A, Zhang J and Jiang D. Anatomic anterolateral ligament reconstruction improves postoperative clinical outcomes combined with anatomic anterior cruciate ligament reconstruction. J Sports Sci Med 2016; 15: 688-696.
[22] Mathai NJ, Amaravathi RS, Pavan KV, Sekaran P, Sharma G and Codanda B. Functional and computed tomography correlation of femoral and tibial tunnels in single-bundle anterior cruciate ligament reconstruction: use of accessory anteromedial portal. Indian J Orthop 2016; 50: 655-660.
[23] Saccomanno MF, Capasso L, Fresta L and Milano G. Biological enhancement of graft-tunnel healing in anterior cruciate ligament reconstruction. Joints 2016; 4: 174-182.