



Original Article

Treadmill training with partial body-weight support after anterior cruciate ligament reconstruction: a randomized controlled trial

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Abstract. [Purpose] To compare the effects of treadmill training with partial body weight support (TTPBWS) and conventional physical therapy (PT) on subjects with anterior cruciate ligament reconstructions. [Subjects and Methods] A total of 40 subjects were randomly allocated to either a treatment group or a control group. Subjects received either treadmill training with partial body weight support (treatment group) or conventional physical therapy (control group). The circumferences of the lower extremities, Holden classifications, 10-meter walking times and the International Knee Documentation Committee (IKDC) scores were compared at 12 and 24 weeks post-operation. The knee joint stability was tested at 24 weeks post-operation using a KT-1000. [Results] Significant differences were found between the two groups at the 12 weeks post-operation. For most of the measures, there was no significant difference between the groups at 24 weeks post-operation. Interestingly, for most of the measures, there was no significant difference between their values in the treatment group at 12 weeks and their values in the control group at 24 weeks post-operation. [Conclusion] The function of a subject's lower extremities can be improved and the improvement was clearly accelerated by the intervention of treadmill training with partial body weight support, without compromising the stability of the knee joints in a given follow-up period.

Key words: Partial body-weight support, Anterior cruciate ligament, Rehabilitation

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is very common in sport activities and traffic accidents, and may lead to an increased risk of meniscus and cartilage damage¹⁾. In order to restore the stability of the joint, enhance proprioception, and regain a normal movement, appropriate surgical treatment and suitable rehabilitation training are necessary²⁾.

At present, there are still some disputes about rehabilitation after reconstruction of the anterior cruciate ligament, regarding the rehabilitation program, the choice of when to begin training, and the outcome evaluation³⁾. Although conventional physical therapy is acceptable, a subject's lower extremities functional recovery may be delayed by concerns over an inflammatory reaction in the knee joint and loosening of the graft.

Treadmill training with partial body-weight support has been shown to be effective in neurologic rehabilitation⁴⁾. Treadmill training follows modern principles of motor learning and allows subjects to practice complex gait cycles early in rehabilitation before they can walk independently⁵⁾. Treadmill training with partial body-weight support and conventional training have been compared after fracture of the femur neck and total hip arthroplasty^{6, 7)}, and both treatment groups showed better and faster recoveries than the control groups. The purpose of this study was to investigate the effect of treadmill training with early partial body weight support on the rehabilitation of anterior cruciate ligament reconstruction. The hypothesis was that

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treadmill training with partial body-weight support would be more effective than conventional physical therapy at improving the lower extremity function of subjects with anterior cruciate ligament reconstruction.

SUBJECTS AND METHODS

Between January 2012 and January 2014, 75 subjects with anterior cruciate ligament reconstruction were recruited, and 40 met our inclusion criteria (Fig. 1). Nineteen subjects did not meet the inclusion criteria and sixteen subjects declined to participate. The inclusion criteria were: unilateral knee injury, preoperative MRI showing a rupture of the anterior cruciate ligament; positive drawer test, Lachman test, and pivot shift test confirming the subjects had knee instability, but did not have meniscus, cartilage, multiple ligament injuries and fractures; willingness to participate in a rehabilitation program; anterior cruciate ligament reconstruction performed by the same group of orthopedic surgeons; and no other orthopedic or neurologic diseases impairing gait.

All the subjects were treated with arthroscopic four strands of anterior cruciate ligament reconstruction using autologous hamstring tendon, and fixed with a button plate and suture plate suspension fixation system. Subjects were randomly and evenly (20 subjects per group) allocated to either the treatment group or the control group by choosing sealed envelopes before the start of the intervention. All 40 subjects were followed up for more than 24 weeks, and the clinical characteristics of the participants are presented in Table 1.

Informed consent was obtained from all participants prior to the study and this study was approved by the local ethics committee (Scientific Research and Ethics Committee of The affiliated Taicang Hospital of Soochow University).

All the subjects were protected by a brace fixed at 0 degrees, to limit the knee angle during training. Subjects attended the outpatient rehabilitation room, according to the plan of rehabilitation training, 3 times per week.

The program of the subjects in the control group was as follows: 1 week post-operation: quadriceps and hamstring muscles isometric contraction, passive joint flexion and extension exercises; 2 to 4 weeks post-operation: protective straight leg raises and partial weight-bearing walking exercises; 5 to 12 weeks post-operation: closed and open chain knee extension, knee extensor resistance exercises, full weight bearing stretched and flexed walking exercises, squat exercise, descending steps, balance board and power bicycle exercise; 13–24 weeks post-operation: start to step forward and backward running, sideways running and the “S” shape running practice.

In addition to performing the same training program as the control group, all subjects in treatment group were asked to perform treadmill training with partial body weight support with a brace limiting knee flexion to 60 degrees from 1 week post-operation. Initially, subjects were encouraged to stand while bearing only some of their weight and shift their gravity during standing. The initial weight-bearing was 30%, with a 20% increase every week, aiming for double lower limb full weight-bearing and the ability to shift gravity stably at 6 weeks. Subjects were trained to get accustomed to the feeling of standing on both legs, and then try gravity shift training with the help of a posture correction mirror and guidance from the therapist to correct their standing position. The initial speed of the treadmill was 0.2 m/s and was increased by 0.2 m/s every week; the slope of the treadmill was always 0 degrees. Full weight-bearing walking training lasted from 7 to 24 weeks post-operation under the protection of crutches at treadmill speeds of 1.0–1.5 m/s.

The assessments included:

- a. Circumference of lower extremities: the circumference of the leg was measured 10 cm above the patella in the supine position, and was compared with the healthy side.
- b. Holden classification: Holden walking capacity classified into 5 levels.

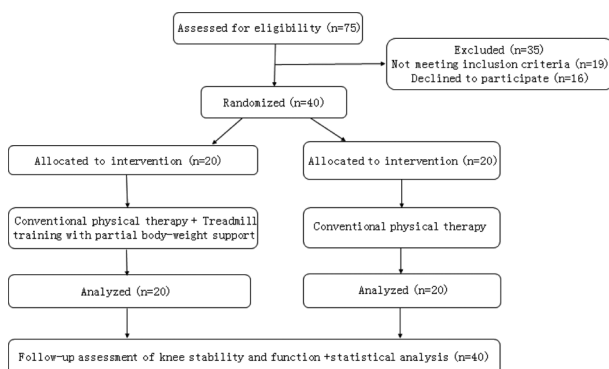


Fig. 1. Flow diagram of the study

Table 1. Clinical characteristics of the participants at the study onset (n=40)

	Treatment group (n=20)	Control group (n=20)
Age (year)	39.6 ± 13.3	45.7 ± 13.9
Male/female (n)	13/7	14/6
Weight (kg)	65.3 ± 7.7	67.8 ± 9.2
Height (cm)	171.2 ± 10.4	175.8 ± 6.5
Body mass index (kg/m ²)	22.2 ± 2.2	23.1 ± 1.8
Left/right (n)	10/10	11/9
Causes of injury(n)		
Sports	15	16
Traffic	5	4

There were no significant differences between the groups at all baseline, $p > 0.05$.

- c. Ten-meter walking time at maximum gait speed: Subjects 10 m walking time at the fastest and most stable gait under the protection of a brace was recorded with an accuracy of 0.1 s.
- d. International Knee Documentation Committee (IKDC): knee functional score was evaluated according to the IKDC score system.
- e. Knee joint stability: the stability of the knee joint was measured with a KT-1000.

The data are presented as the mean ± standard deviation. The results were analyzed using the t-test, χ^2 test and two-way ANOVA. The statistical software, SPSS 20.0 (IBM, USA), was used for the statistical analysis. The level of significance was chosen as 0.05.

RESULTS

All subjects received a full follow-up of more than 24 weeks. No one had post-operative knee swelling, effusion or infection. Significant differences ($p < 0.05$) were found in the Holden classification, 10-meter walking time, circumference of the lower extremities and IKDC scores between the two groups at 12 weeks post-operation. For most of the measures, there was no significant difference ($p < 0.05$) between the two groups at 24 weeks post-operation (Table 2).

Interestingly, the values of the circumference of lower extremities, Holden classification and 10-meter walking time at 12 weeks post-operation in the treatment group were not significantly different from their respective values in the control group at 24 weeks post-operation ($p > 0.05$; Table 3).

DISCUSSION

Anterior cruciate ligament injury may affect the stability of the knee joint, and the proposition that early reconstruction helps to prevent secondary knee osteoarthritis and meniscus injury has become the consensus. However, the operation can only restore the static structural stability, while dynamic stability and knee function recovery require early scientific and appropriate rehabilitation training. Traditional rehabilitation program options can generally be divided into conservative rehabilitation programs and aggressive rehabilitation programs^{8,9}. The former have the problems of a long recovery period and low satisfaction among subjects, while the latter have the risk of implant loosening, bone tunnel enlargement and swelling of the joint. Therefore, rehabilitation should vary from person to person and be based on the principle of appropriate rehabilitation¹⁰. In view of the fact that subjects after ACL reconstruction can't bear their total body-weights and to compensate for the slow recovery of the knee joint, we introduced treadmill training with partial body-weight support into the rehabilitation program.

Table 2. Clinical results

	Group	IKDC	KT1000 (mm)	Difference in the circumference (cm)	Holden	10 m walking time (s)
12 weeks	Treatment (n=20)	63.14 ± 10.92*	N/A	0.94 ± 0.39 [#]	4.25 ± 0.44 [#]	8.58 ± 1.83 [#]
	Control (n=20)	52.49 ± 6.43	N/A	1.66 ± 0.38	3.24 ± 0.44	12.70 ± 0.39
24 weeks	Treatment (n=20)	81.92 ± 10.74 [#]	2.00 ± 0.97	0.63 ± 0.24	4.50 ± 0.51	7.57 ± 1.09
	Control (n=20)	76.94 ± 9.49	2.10 ± 0.70	0.78 ± 0.29	4.43 ± 0.51	7.82 ± 1.25

*Significant difference between groups, $p < 0.05$

[#]Significant difference between groups, $p < 0.01$

Rest, $p > 0.05$

N/A: Not available

All results are expressed as the mean ± standard deviation.

Table 3. Clinical results

	Group	IKDC	KT1000 (mm)	Difference in the circumference (cm)	Holden	10 m walking time (s)
12 weeks	Treatment (n=20)	63.14 ± 10.92 [§]	N/A	0.94 ± 0.39	4.25 ± 0.44	8.58 ± 1.83
24 weeks	Control (n=20)	76.94 ± 9.49	2.10 ± 0.70	0.78 ± 0.29	4.43 ± 0.51	7.82 ± 1.25

[§]Significant difference between groups, $p < 0.01$

Rest, $p > 0.05$

N/A: Not available

All results are expressed as the mean ± standard deviation.

Walking is a complex and random movement that involves muscles of the whole body cooperating to produce body displacement¹¹. The discomfort and instability of the knee joint after ACL reconstruction can lead to varying degrees of decline in walking efficiency¹². The first demand of subjects undergoing any surgery involving a low extremity joint is restoration of the pre-injury walking condition, and this requires an improvement in the cooperative motion of multiple joints, as well as the strength of the lower limb muscles. However, during this period, subjects often exhibit abnormal gait patterns due to pain from lower limb swelling, lack of muscle strength and imbalance of the contralateral side¹³. Treadmill training with partial body-weight support has already been shown to be effective in neurologic rehabilitation⁴. Treadmill training with partial body-weight support provides a safer environment for the recovery of walking ability, gait correction and balance adjustment than traditional physical therapy. It combines weight-bearing, stepping and stable balance, known as the three elements of walking, to promote the formation of normal gait patterns¹⁴. Furthermore, treadmill training with partial body weight support is beneficial for the restoration of the stability of positional control and limb coordination.

Some researchers have reported that early activity training might cause joint laxity, and encourage joint inflammation and joint effusion¹⁵. Treadmill training with partial body weight support reduces the muscle's contraction load on the lower extremity and promotes the development of lower extremity muscle strength, as well as activity and weight-bearing capacities with a low demand on muscle strength¹⁶. Moreover, treadmill training with partial body weight support can also make up for the absence of closed kinetic chain training in the early stages due to insufficient muscle strength. In the present research, significant differences were found between the two groups ($p < 0.05$) at the 12 weeks post-operation in the Holden classifications, 10-meter walking time, the circumferences of the lower extremities and IKDC scores. Interestingly, the circumference of the lower extremities, Holden classification and 10-meter walking time ($p > 0.05$) values at 12 weeks post-operation in the treatment group were not significantly different from their respective values in the control group at 24 weeks post-operation, indicating that treadmill training with partial body weight support improved walking stability and accelerated the rehabilitation process by stimulating the coordination and balance functions of each muscle group¹⁷.

However, researchers have reported that early active rehabilitation may increase the risk of implant loosening by blocking the revascularization process around the implant¹⁸. Closed kinetic chain exercise elicits good recovery of knee joint function with low implant tension, while open kinetic chain exercise better elicits muscle strength¹⁹. Treadmill training with partial body weight support gait training can be considered as a semi-open and semi-closed kinetic chain motion because of its low demand on muscle strength. The tension of the knee joint is largest between 0–60 degrees, so the limiting angle was set to 60 degrees in the training. The results show that treadmill training with partial body weight support did not increase the risk of implant loosening or rupture, and was a relatively safe way of moving, but the long-term effects on joint stability need further observation.

Treadmill training with partial body weight support varies from person to person depending on the different features of the subject, and more attention should be paid to strengthening the gluteal, quadriceps, hamstring and gastrocnemius muscles, in order to facilitate future gait training²⁰. Throughout the training process, the principle of slow and accurate, but not fast and unstable should be adhered to. Special attention should be paid to the relationship between protection and training, and treadmill training with partial body weight support provides a novel path to successful rehabilitation in a way that gives the precise attention required. It can improve and accelerate the improvement of function of a subject's lower extremities without compromising the stability of the knee joint in a given follow-up period.

Limitations of this study were small sample size and the short-term follow-up period. The long-term stability of the knee, lower limb function and gait changes need further observation. Stability tests relied on a physical examination, not magnetic resonance examination, therefore, tendon bone healing and bone tunnel expansion could not be observed. At our hospital, all anterior cruciate ligament reconstruction operations are performed at the acute stage, so a preoperative evaluation cannot be carried out as accurately as postoperatively. A further control study is needed involving chronic anterior cruciate ligament injury patients as subjects.

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