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ORIGINAL RESEARCH ARTICLE

Effect of One-Leg Cycling Aerobic Training in Amateur Soccer Players After Anterior Cruciate Ligament Reconstruction

ABSTRACT

Olivier N, Weissland T, Berthoin S, Legrand R, Rogez J, Thevenon A, Prieur F: Effect of one-leg cycling aerobic training in amateur soccer players after anterior cruciate ligament reconstruction. Am J Phys Med Rehabil 2009;88:362–368.

Objective: To examine before and after 6 wks of rehabilitation, the cardiorespiratory fitness, and resting cardiac parameter changes in soccer players having undergone anterior cruciate ligament reconstruction and to assess the benefits of a one leg cycling aerobic training program with the nonsurgical leg during the rehabilitation period.

Design: Twenty-four amateur soccer players took part in this study. The subjects were then randomly assigned to one of two groups—either an individualized one leg cycling aerobic program (training group) or without cardiorespiratory training (control group). The initial evaluation (T1) was carried out the first day of rehabilitation and the final evaluation (T2) within 42 days. Both consisted of resting cardiac echography measurement and maximal graded tests performed with the nonsurgical leg.

Results: For training group, peak power output, peak minute ventilation, the first (VT1), and second (VT2) ventilatory threshold values were significantly ($P < 0.05$) higher at T2 than at T1 (+13%, +10%, +7%, and +11%, respectively). For control group, peak power output, peak oxygen uptake, peak minute ventilation, and VT2 values decreased significantly at T2 in comparison with T1(−10%, −10%, −12%, and −11%, respectively). After hospitalization, significant reductions in end diastolic volume (T1, 116 ± 17 ml; T2, 97 ± 16 ml; $P < 0.05$) and stroke volume (T1, 75 ± 14 ml; T2, 59 ± 12 ml; $P < 0.05$) were also observed. For training group, the cardiac parameters were similar between T1 and T2.

Conclusion: These results suggest that one leg cycling training during the rehabilitation seems to be an adapted method to stop the effects of hypoactivity.

Key Words: Aerobic Exercise, Surgery, Deconditioning, Stroke Volume

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Because of the current popularity of physical activities and sports, knee trauma is often observed among soccer players of all ages. Specifically, knee injuries related to the anterior cruciate ligament are often reported in soccer players.[1] Ruptures of the ligament entail a lack of knee stability to perform some movements. To resume sporting activities, surgical reconstruction is generally recommended. This operation inevitably leads to a phase of reduced activity and physical deconditioning.[2] The consequence of a physiologic deconditioning includes a decrease in work capacity[3,4] associated with hematologic,[5] musculoskeletal,[6] metabolic,[6] thermoregulatory,[7] and cardiovascular[8] impairments. To limit this deconditioning, therapeutic treatment using aerobic exercises performed with healthy limbs, i.e., one leg or two arms, could be offered to the patient.[9] The maximal cardiorespiratory values are not different between arm cranking or one-leg cycling (OLC).[10] However, the perceived exertion is lower when the exercises are performed with the lower limb. Thus, after knee-surgery, physiologic and perceptual responses indicate that OLC seemed to be a better adapted method for aerobic reconditioning.[10]

Concerning the OLC training protocols, the literature shows a great heterogeneity in the intensities, frequencies, and durations of the exercise phases generally proposed.[11–15] It seems that, to obtain significant physiologic adaptations, three weekly sessions are necessary. Programming 30- to 45-min sessions, with intensities ranging between 70% and 100% of peak oxygen uptake (VO_{2peak}) can generate an improvement of more than 30% compared with the initial VO_{2peak}. The increase in aerobic fitness after OLC training would mainly seem to be due to peripheral vascular adaptations.[15,16] Indeed, the improvement in maximal oxidative capacity observed during exercise with the trained limb does not seem to be related to an enhanced central cardiac function, but rather to an increased vascularization of the active leg.[15,16] However, for subjects with a lower aerobic capacity, this kind of training could also generate central adaptations (cardiovascular) and not only peripheral, as observed in active subjects.[17]

To our knowledge, no study has explored the effects of OLC training on the physical recovery of patients in a hospital context. The objective was to assess the beneficial effects induced by an endurance training program during a rehabilitation period. We hypothesized that individualized OLC training during the rehabilitation phase accelerates the cardiorespiratory reconditioning of the patients when compared with standard rehabilitation.

METHODS

Subjects

Twenty-four male regional level soccer players (4.7 ± 0.3 hr $wk^{-1}$of physical activities) took part in this study. Their mean age, height, and body mass were 24.2 ± 3.8 yrs, 1.80 ± 0.06 m, and 77.2 ± 3.9 kg, respectively. They had undergone surgical reconstruction of the anterior cruciate ligament of the knee: central third bone patellar tendon bone autograft (21 subjects) and doubled semitendinosus/doubled gracilis autograft techniques (3 subjects). Between the initial trauma and the surgical operation, all subjects suspended sports-related activities for at least 2.0 ± 0.2 mos and for this period no standard treatment program was imposed. The study was carried out only with volunteers who had been informed as to the methods, protocol, and procedures used (written and signed consent) and with the agreement of the physicians in charge of rehabilitation. Subjects showing a hemoglobin rate lower than 12 g/100 ml were excluded from the experimentation. The protocol was approved by the Hospital Ethical Committee and complied with the ethical standards of the 1975 Helsinki Declaration.

Experimental Design

Subjects were randomly divided into 2 groups of 12 subjects by drawing lots. The control group (CG) carried out a rehabilitation program without cardiorespiratory training, whereas the training group (TG) received the rehabilitation program and additional OLC training sessions. Evaluations were carried out before and after rehabilitation at an interval of 6 wks. The evaluations were always carried out in the morning, under identical conditions. Both consisted of resting cardiac echography and maximal graded tests with the nonsurgical leg.

Maximal Graded Test

The one-leg exercise (nonsurgical leg) was performed on a standard bicycle ergometer at a cadence of 65 rev min^{-1}. The only special arrangement for this exercise was to secure the foot on the pedal with a toe clip and an elastic band around the heel. The foot of the nonworking leg was placed on a small chair placed beside the bicycle. The tests began with an imposed power of 55 W for 2 mins, then the power was increased by 10 W every 2 mins.[18] Subjects were the highest possible stage and were encouraged throughout the tests. The exercises were considered maximum if: respiratory exchange ratio was higher than 1.10 and heart rate (HR) reached the theoretical maximum value i.e., when HR was within 10 beats per min (bpm) of the predicted maximal value using the Karvonen's method (age, 220).[15] All subjects met these criteria.

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Cardiorespiratory Parameter Measurements

The gas exchange parameters, VO_2, carbon dioxide production (VCO_2), and minute ventilation (VE) were continuously measured in breath-by-breath mode with a cardiopulmonary exercise test system. Before each test, the analyzers were calibrated with two gas mixtures of known concentration. Gas exchange data were averaged every 15 secs. The HR was monitored every 5 secs and data were averaged during 15 secs. Identification of the first (VT1) and second (VT2) ventilatory thresholds were carried out using the methods of Beaver et al.[19] and Wasserman et al.,[20] respectively. VT1 and VT2 represented ventilatory compensation for increasing metabolic acidosis and was related to perceived effort and performance.[19] The ventilatory thresholds were expressed in Watts.

Echocardiographic Examination

Transthoracic echocardiography at rest was carried out with a Sonos 5500 ultrasound system using a 2.5 MHz phased array transducer. It was performed by an experienced cardiologist, who possessed no information on the patients' clinical data. Recordings were taken with the patients in the left lateral decubitus position. Left ventricular end diastolic, and end systolic volumes were measured from the apical four-chamber view using the modified Simpson rule, according to the methodology from the American Society of Echocardiography.[21] Only representative cycles were measured and the averages of the three best measurements were taken. The endocardial border was traced, excluding the papillary muscles. The frame captured at the R wave of the electrocardiogram was considered to be the end diastolic frame, and the frame with the smallest left ventricular cavity, the end systolic frame. Stroke volume and ejection fraction at rest were calculated as follows: stroke volume (milliliter) = (end diastolic volume − end systolic volume), ejection fraction (%) = ([end diastolic volume − end systolic volume]/[end diastolic volume]). Resting HR was measured with a HR monitor. Subjects were placed in the dorsal decubitus position in calm conditions. Measurements were made and averaged during 10 mins after a 10-min quiet period.

Standard Rehabilitation Program

On the first postoperative day, all patients were encouraged to walk with full weight bearing and full knee extension. The protocol emphasizes restoring full extension and quadriceps function as soon as possible. Progression was based on a 6-wk period, being guided by the presence and degree of pain and swelling. Quadriceps strengthening exercises were restricted to closed kinetic chain exercises during the first 2 mos. The key to bridging the gap between rehabilitation and sports application is to return to basic fundamental movement skills. This begins with postural awareness exercises, balance activities, proprioceptive challenges, coordination activities, and basic functional strengthening drills. Patients were allowed to ride an exercise cycle from 5 to 6 wks postoperatively and to begin gymnasium exercises (squats) from 8 wks.[22]

Cardiorespiratory Training Program

In addition to the classical rehabilitation program, the 12 subjects of the TG benefited from a specific training program with the nonsurgical leg (standard bicycle ergometer). The training program was individualized according to HR and was of an intermittent type, also called interval training. It consisted of several series of exercises alternated with active recovery periods whose intensities were low or moderate. To adapt the protocol to the rehabilitation constraints, the subjects were trained for 21 mins, by alternating 3 mins at 70% and 3 mins at 85% of HR_{peak}. They totaled 18 sessions spread during 6 wks (3 sessions per week). At each training session, a HR monitor was used for HR control and, thus, to check if the intensity of the proposed exercise was well adapted. During the rehabilitation program, the CG carried out five sessions (10 mins per week) with very low intensity (30 W) to become familiarized with the cranking gesture.

Statistical Analysis

Data are expressed as means ± standard deviations. The normality distribution of the data was checked with the Kolmogorov-Smirnov test. A two-way analysis of variance was used to test for an effect or interaction of experimental factors at each time condition. Tukey's post hoc test was used to compare the maximal and submaximal values. The $P < 0.05$ level was accepted as significant for all tests.

RESULTS

In Table 1 the cardiorespiratory data before (T1) and after (T2) rehabilitation are presented. For TG, after the rehabilitation program, peak power output (W_{peak}) VE_{peak}, VT1, and VT2 values were significantly higher at T2, when compared with T1 (+13%, +10%, +7%, and +11%, respectively). For CG, W_{peak}, VO_{2peak}, VE_{peak}, and VT2 values were significantly lower (−10%, −10%, −12%, and −11%, respectively). At each submaximal power, TG demonstrated significantly lower values for HR (Fig. 1). Conversly, for CG, submaximal values were significantly higher at T2 (Fig. 2).

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TABLE 1 Graded test parameters (mean ± SD) before (T1) and after (T2) rehabilitation for the control group (CG, n = 12) and the training group (TG, n = 12)

	W_{peak}, W	VO_{2peak}, (ml min^{-1} kg^{-1})	VE_{peak}, L min^{-1}	HR_{peak}, bpm	SV1, W	SV2, W
T1 TG	132 ± 9	28 ± 4	83 ± 17	188 ± 9	63 ± 7	86 ± 9
T1 CG	133 ± 11	29 ± 4	86 ± 21	184 ± 7	69 ± 5	90 ± 9
T2 TG	152 ± 9[a]	30 ± 5	92 ± 20[a]	191 ± 8	73 ± 8[a]	97 ± 8[a]
T2 CG	120 ± 10[a,b]	26 ± 4[a,b]	76 ± 16[a,b]	185 ± 5	71 ± 5	80 ± 8[a,b]

[a] Significantly different between T1 and T2, $P < 0.05$.
[b] Significantly different compared with the training group, $P < 0.05$.
W_{peak}, peak power output; VO_{2peak}, peak oxygen uptake, VE_{peak}, peak minute ventilation; HR_{peak}, peak heart rate; SV1, first ventilatory threshold; SV2, second ventilatory threshold.

The averaged variations in resting cardiac parameters measured with echocardiography are presented in Table 2. For CG, a significant reduction in end diastolic volume (T1, 116 ± 17 ml; T2, 97 ± 16 ml; $P < 0.05$) and stroke volume (T1, 75 ± 14 ml; T2, 59 ± 12 ml; $P < 0.05$) were observed at T2. The resting HR was significantly higher (T1, 69 ± 11 bpm; T2, 76 ± 13 bpm, $P < 0.05$). For TG, the cardiac parameters were similar between T1 and T2.

DISCUSSION

The objective of this study was to examine cardiorespiratory fitness changes in subjects having undergone anterior cruciate ligament reconstruction and to assess the benefits of an OLC aerobic training program performed during the rehabilitation period.

TG: Rehabilitation Program and OLC Training

After rehabilitation, at each submaximal power, TG demonstrated significantly lower values for HR (Fig. 1) and both the first and second VT appeared at higher absolute power output values. These data are in agreement with the results of the literature.[12–14] At maximal intensities, W_{peak} was 13% higher and VE_{peak} 11% higher after the OLC training. Contrary to some authors[12,15,23] who reported a significant increase in VO_{2peak} after OLC training (+14%–33%), we failed to observe a significant increase in VO_{2peak} after the training program (T1, 28 ± 4 *vs.* T2, 30 ± 5 ml min^{-1} kg^{-1}; not significant). The studies that showed an increased aerobic fitness by means of OLC exercises proposed a 2-mo training program with 30- to 45-min sessions.[8,11,13,23] In a rehabilitation context, training is much shorter and corresponds to the patient's time of hospitalization and to his health status. Because of the specific multifield nature of the care, made up of physical therapy and physical training, the sessions were adapted by necessity. This element could explain the unchanged values of VO_{2peak} in the present study.

OLC could involve specific adaptations, which would be peripheral rather than central.[15,16] Indeed, the increase in the maximal oxidative poten-

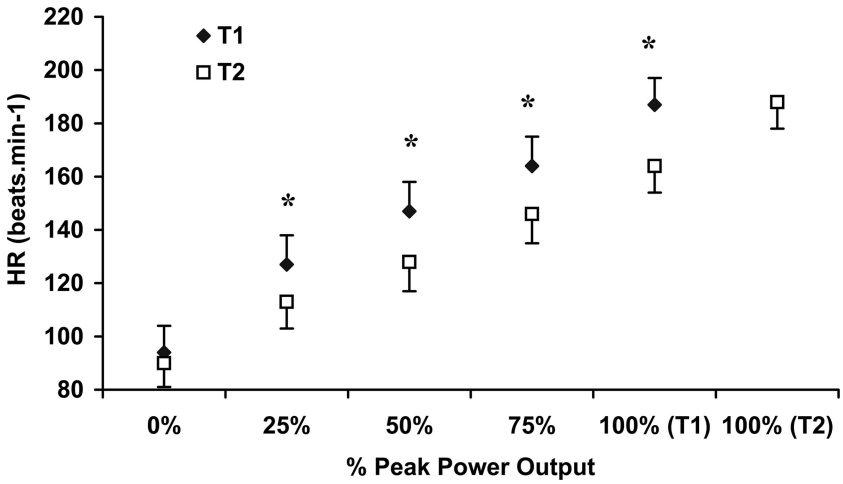

FIGURE 1 *Heart rate (HR) values (mean ± SD) of TG recorded at each stage of the graded test, before (T1) and after rehabilitation (T2). HR data were compared at 25%, 50%, 75%, and 100% of* W_{peak} at T1.

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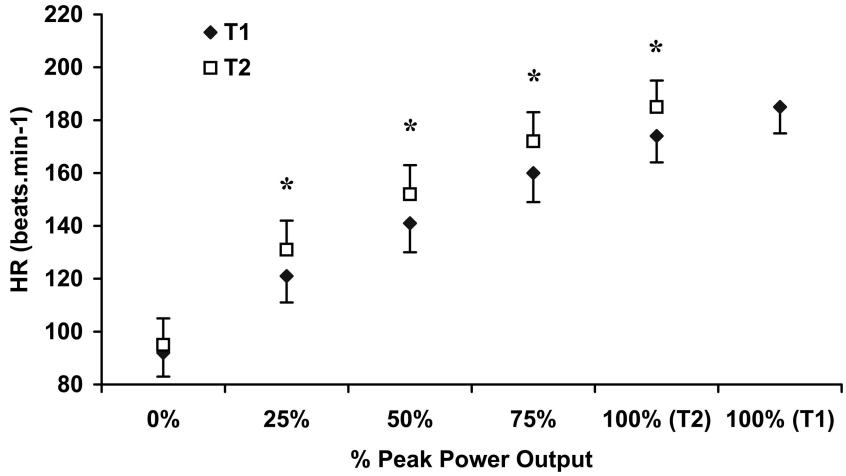

FIGURE 2 *Heart rate (HR) values (mean ± SD) of CG recorded at each stage of the graded test, before (T1) and after rehabilitation (T2). HR data were compared at 25%, 50%, 75%, and 100% of* W_{peak} at T1.

tial when training with a small muscular group could be mainly due to an improvement in the vascularization of active tissue.[15] After several weeks of OLC training, the increase in capillarization would be possible, allowing an increase in maximal muscle blood flow.[24] Our program was probably not sufficient to induce an increase in maximal cardiac output. Similar values of cardiac parameters at rest in TG (Table 2) support this assumption. With longer protocol durations, some authors recorded higher maximal cardiac output after OLC training.[13,15] Nevertheless, the lack of change in the left ventricular dimensions, mass, and performance (index of contractility) after the OLC training suggested that intrinsic cardiac adaptations are not necessary to achieve such an increase in maximal cardiac output.[15] An increase in the venous return could induce modification of cardiac output.[13,14]

Even though our results testify to a significant improvement of the respiratory function, this must be taken with caution. Knowing that performance increase is not only due to a metabolic improvement, but also to gesture effectiveness, the subjects during the training period organized in an economic process; this strategy could explain partly the increase in W_{peak} (+13%). Nevertheless, OLC seems to be an effective means to limit deconditioning. More especially, this training does not seem to worsen the muscular recovery of the injured limb. At 4-mo postsurgery, the isokinetic performance of knee extensor muscles of the injured leg was significantly lower as compared with that of the healthy leg (peak torque at 90 degrees/sec, −26%; power at 180 degrees/sec, −14%; total work at 240 degrees/sec, −19%), but this deficit was identical for the two groups.

CG: Rehabilitation Program Without Cardiorespiratory Training

After 6 wks of rehabilitation without an aerobic training program, a fast and significant ($P < 0.05$) reduction in aerobic fitness was observed: a 10% drop in VO_{2peak} and a 10% drop in W_{peak}. The first and second VT appeared at lower absolute power output values testifying to a reduction in aerobic fitness (Table 1). At rest and submaximal intensities, HR values were higher (Table 1 and Fig. 2). Some authors have suggested that the higher HR observed after prolonged confinement could mainly

TABLE 2 Cardiac parameters, before (T1) and after (T2) rehabilitation for control group (CG, n = 12) and training group (TG, n = 12)

	EDV, ml	ESV, ml	SV, ml	EF, %	HR, bpm
T1 TG	110 ± 14	42 ± 8	68 ± 13	62 ± 8	73 ± 8
T1 CG	116 ± 17	41 ± 11	75 ± 14	65 ± 9	69 ± 11
T2 TG	108 ± 12	40 ± 10	68 ± 12	63 ± 7	75 ± 9
T2 CG	97 ± 16[a]	38 ± 11	59 ± 12[a,b]	61 ± 5	76 ± 13[a]

[a] Significantly different between T1 and T2; $P < 0.05$.
[b] Significantly different compared with training group, $P < 0.05$.
EDV, end diastolic volume; ESV, end systolic volume; SV, stroke volume; EF, ejection fraction; HR, heart rate at rest.

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result from a reduction in stroke volume and cardiac vagal activity.[7] Our data are not easily comparable with those of the literature because, to our knowledge, no study has treated the effect of a hospitalization on the deconditioning fitness under real conditions. The protocol[13,15,23] only partially reflects the reality of anterior cruciate ligament reconstruction.

The reduction in aerobic fitness could be explained by an alteration in cardiovascular function. In soccer players, 7 days of hospitalization due to knee surgery led to resting cardiac deconditioning characterized by a significant reduction in the stroke volume.[25] During the 6 wks of hospitalization without an aerobic training program, the physical deconditioning continued (Table 2). The decrease in blood volume[3,5] is largely responsible for the observed alteration in cardiovascular function during periods of inactivity. After such periods, the reduced blood volume has been associated with reduced plasma volume and venous return.[4] Many studies have demonstrated that ~70% of the alteration in VO_{2max} can be explained by a decrease in plasma volume.[8,25] This assumption was confirmed by the data of echocardiographic measurements (Table 2). In the present study, 6 wks of rehabilitation without an aerobic training program led to a significant ($P < 0.05$) 21% reduction in stroke volume. As explained by Starling's law,[26] the stroke volume is dependent on the degree of stretch of the ventricular walls.

It would seem that the progressive resumption of walking, quadriceps strengthening exercises, and various techniques suggested during rehabilitation[27] would have little effect on the process of reconditioning subjects. To preserve the benefit of training, Hickson et al.[28] suggested that the intensity of the exercise phases should be around 70% of VO_{2peak} with at least three sessions per week. These results suggest that the aerobic program during the rehabilitation phase was essential for recovering. However, movement using crutches requires higher energy expenditure than normal walking.[29] It could not constitute a sufficient exercise to allow the initial aerobic fitness level to be restored. Comparatively with TG, the control subjects had lower values and were behind with their physical condition, to resume sporting activity. Therefore, although aware of their deficits, soccer players who are eager to regain their place in their soccer teams as fast as possible are likely to not to respect the therapist's instructions, thus increasing recurrence.

CONCLUSION

In soccer players, 6 weeks of hospitalization due to anterior cruciate ligament reconstruction led to resting cardiac deconditioning characterized by a significant reduction in stroke volume. Without cardiorespiratory training, a fast and significant reduction in aerobic fitness was observed. OLC seems to be an effective means to limit deconditioning. These elements should encourage the hospital practitioner to propose a program of aerobic training involving the healthy limbs in addition to conventional rehabilitation.

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