Aerobic fitness in professional soccer players after anterior cruciate ligament reconstruction

Adriano Marques de Almeida[¤]*, **Paulo Roberto Santos Silva**^{¤◉}, **André Pedrinelli**^{¤◉}, **Arnaldo J. Hernandez**^{¤◉}

Sports Medicine Discipline, Instituto de Ortopedia e Traumatologia, Hospital das Clínicas HCFMUSP, Faculdade de Medicina, Universidade de Sao Paulo, Sao Paulo, SP, Brazil

◉ These authors contributed equally to this work.
¤ Current address: Rua Dr. Ovidio Pires de Campos, 333, Cerqueira Cesar, Sao Paulo, Sao Paulo, Brazil
* adrianoalmeida@usp.br

Abstract

Although anterior cruciate ligament (ACL) reconstruction is considered a successful procedure in restoring knee stability, few studies have addressed the issue of aerobic capacity after ACL surgery. Soccer players need technical, tactical and physical skills to succeed, such as good knee function and aerobic capacity. Our purpose is to evaluate aerobic fitness in ACL injured professional football players and six months after ACL reconstruction compared to a control group. Twenty athletes with ACL injury were evaluated and underwent ACL reconstruction with hamstrings autograft, and were compared to twenty healthy professional soccer players. The methods used to evaluate aerobic fitness were maximum oxygen uptake (VO_{2max}) and ventilatory thresholds with a treadmill protocol, before and six months after surgery, compared to a control group. Knee function questionnaires, isokinetic strength testing and body composition evaluation were also performed. Results: Median ACL-injured patients age was 21 years old, and controls 20.5 years old. (n.s.). Preoperative VO_{2max} in the ACL injured group was 45.2 ± 4.3 mL/kg/min, postoperative 48.9 ± 3.8 mL/kg/min and controls 56.9 ± 4.2 mL/kg/min. (p< .001 in all comparisons). Body composition evaluation was similar in all situations. Knee function questionnaires and quadriceps peak torque deficit improved after surgery but were significantly lower compared to controls. Conclusion: Aerobic fitness is significantly reduced in professional soccer players with ACL injury, and six months of rehabilitation was not enough to restore aerobic function after ACL reconstruction, compared to non-injured players of the same level.

Introduction

Anterior cruciate ligament (ACL) injury is one of the most frequent severe knee injuries in soccer players.[1] The advances in surgical techniques have resulted in good surgical outcomes and increased the potential for an athlete to return to his previous level of sport activity.[2] Many studies outline criteria to successfully return to sport with minimum risk of reinjury.

These criteria include time after ACL reconstruction (ACLR), knee stability, isokinetic strength tests, hop tests and self-reported questionnaires. [3–5] Although most studies list six months as the time period allowed for return to sports[6], it has been shown that most athletes do not meet these criteria at this period[4,5], and up to 45% of participants do not return to their preinjury level of sports participation.[7]

Soccer players need technical, tactical and physical skills to succeed, including high endurance capacity and strength.[8,9] During a 90-minute game, soccer players run about 10km at an average intensity close to the anaerobic threshold.[8] Maximum oxygen uptake (VO_{2max}) is defined as the highest rate at which oxygen can be taken up and utilized by the body during severe exercise. It is the most common method to evaluate cardiorespiratory fitness of an individual. [10,11] A VO_{2max} of 60 ml/kg/min has been suggested as the minimum fitness requirement for male soccer players to play at elite level. [8,9,12] However, few studies have addressed the issue of aerobic capacity of professional soccer players after ACL reconstruction. [13–15]

The purpose of this study was to evaluate aerobic fitness in ACL injured professional soccer players, before and six months after ACL reconstruction, compared to a control group of non-injured professional soccer players. A secondary aim was to evaluate ventilatory thresholds and running speeds, body composition, isokinetic knee strength and self-reported knee function questionnaires.

Materials and methods

This was a prospective case-control study to evaluate aerobic fitness of professional soccer players with ACL injury and after ACL reconstruction, compared to professional players without knee injury.

This study took place at the Sports Medicine Department of University of São Paulo. This study followed the ethical statements of the Declaration of Helsinki and was approved by the University of São Paulo Medical School Institutional Review Board (protocol 368105) and registered in a public registry (NCT02674282). Written informed consents explaining the study objectives, procedures, benefits and risks were obtained from all participants. The inclusion criteria were ACL injury, professional outfield soccer player, male gender, absence of open physes. Exclusion criteria were associated ligament lesions requiring surgical repair or reconstruction, knee effusion, impossibility to perform the running test, previous knee surgeries, post-operative infection, arthrofibrosis, ACL reconstruction failure, inadequate follow-up. Inclusion criteria for controls were the same, except for ACL injury, or any previous injury that required surgical treatment.

In total, 29 ACL injured patients met the inclusion criteria. Four patients declined to participate. One patient had a bucket-handle meniscus injury and was unable to complete the running test. Twenty-five patients were enrolled to the study. Four ACL injured patients were lost to follow-up, and one patient was excluded due to a cyclops lesion that needed a reoperation during the study. Therefore 20 patients completed the study. The median time between injury and surgery was 3 months (range 1 to 12 months). The control group consisted of 20 soccer players from local lower division professional soccer teams that were performing routine evaluations at our facility.

The measurements were performed prior to the surgery and six months after ACL reconstruction in the ACL group, and were compared to their pre-operative values, as well as to a control group.

Cardiopulmonary exercise testing

The primary outcome of this study was the maximum oxygen uptake (VO_{2max}) of professional soccer players six months after ACL reconstruction, compared to pre-operative and controls

results. Cardiopulmonary exercise test on a treadmill was used to evaluate VO_{2max} and ventilatory thresholds with a modified Heck protocol.[11]

The tests were performed in the afternoon, starting at 01:00 PM, in our laboratory, at room temperature ranging from 20˚C to 24˚C, relative air humidity between 45% and 65% and barometric pressures from 698 mmHg to 705 mmHg. The athletes were advised to avoid high intensity exercises during the 24 hours preceding the test and not to have drinks with caffeine or alcohol on the evaluation day. They had a light meal 1 to 2 hours before the test and came for the test dressed in T-shirts, shorts and running shoes.

An electrocardiogram with 13 derivations (Heartware, Ergo13, Belo Horizonte, Brazil) was recorded during rest, effort and recovery phase. Arterial blood pressure was measured indirectly using an aneroid sphygmomanometer (Tycos, USA) at the end of each stage of the test. The equation 208 –(0.7 x age) was used to find maximal heart rate.[16]

Cardiopulmonary exercise testing using a modified Heck protocol was performed on a motorized treadmill (h/p/cosmos®, Pulsar, Germany). The test began at 8.4 km/h, with increments of 1.2 km/h every two minutes. The inclination was fixed at 2%. The quantity of oxygen (O_2) consumed, carbon dioxide (CO_2) produced and pulmonary ventilation (V_E) were measured breath-by-breath with a computerized gas exchange analysis system (CPX/ULTIMA™, MGC Diagnostics®, Saint Paul, MN, USA) calibrated before each test. The data was analyzed with BreezeSuite™ 6.4.1 cardiorespiratory diagnostic software (MGC Diagnostics®, Saint Paul, MN, USA).

We considered the test had reached its maximum when the players attained 2 of the following criteria: 1) respiratory exchange ratio (VCO_2/VO_2) $\geq$ 1.10; 2) Borg's scale of subjective perception of tiredness $\geq$ 18 and 3) a constant heart rate (HR) varying within 5 beats/min of the predicted. The VO_{2max} was quantified by one of the authors (PRSS), an experienced sports physiologist, when the VO_{2max} increased less than 2 mL/kg/min between two consecutive stages in the peak of the exercise. We also determined two ventilatory thresholds (VTs) during the test.[17] The first ventilatory threshold (VT_1) was determined when we observed the lowest ventilatory equivalent of oxygen (V_E/VO_2) before its continuous increase, and the lowest end-tidal oxygen tension ($PETO_2$) before its continuous increase. The second ventilatory threshold (VT_2) was determined when we observed the lowest ventilatory equivalent of carbon dioxide (V_E/VCO_2) before its continuous increase and the highest end-tidal carbon dioxide tension ($PETO_2$) preceding its abrupt fall (second inflection of curves in progressive exercise). This is the transition between "steady" and "heavy" paces. We also determined the running speed and the percentage of VO_{2max} in which the VT_2 occurred.

Body composition, isokinetic strength and knee function evaluations

Body composition evaluation was performed before the running test. We used a tetrapolar bioelectrical impedance analyzer (InBody 230, Seoul, Corea) to measure weight, fat-free mass (FFM), body fat (BF) and body mass index (BMI). The evaluation was performed in the morning, before lunch. We measured height and oriented individuals to void before the test.[18]

Strength measurement of knee extensors and flexors muscles were performed using an isokinetic dynamometer (Biodex System 3 Pro, Biodex Inc. NY, USA). The subjects performed a 5-minute warm-up on a cycloergometer before the evaluations were conducted. The test consisted of a series of five maximal concentric flexion and extension movements at a constant angular velocity of 60˚/s and twenty flexion and extension movements at a constant angular velocity of 240˚/s. Peak torque of knee extensors and knee flexors muscles were normalized by body mass. We also quantified the peak torque deficits comparing the injured and non-injured limbs.[19]

Participants completed self-reported knee function questionnaires Lysholm and International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, both validated to use in the Brazilian population. [20,21]

Surgical procedure

A single surgeon performed all ACL reconstructions with the same surgical technique. Cefazolin (1g via the intravenous route) was administered prophylactically. Patients were positioned supine in the operating table. Under regional anesthesia, air tourniquet was applied to the proximal thigh with a pressure of 350mmHg. A longitudinal 3 to 4 cm incision was made in the anteromedial aspect of the proximal leg. The semitendinosus and gracilis tendons were identified, released from their insertions on the tibia and harvested with a tendon stripper. The tendons were cleaned of soft tissue and folded to prepare a 4-stranded graft. Anatomic ACL reconstruction was performed arthroscopically. The femoral tunnel was drilled inside out through the anteromedial portal in the ACL footprint.[22] Femoral fixation was performed with a continuous loop fixed-length cortical suspension device (endobutton)[23] for all patients. The tibial tunnel was drilled outside in at the center of the ACL footprint and the graft was fixed within the tibia with metallic interference screw.

Statistical analysis

A pilot study was performed *a priori* with six soccer players with ACL injury. In this group VO_{2max} was 41.91 ± 5.59 ml/kg/min. Based on previous studies [13,24,25] we considered that a VO_{2max} variation of 15% would be clinically significant, and calculated the sample size for a level of significance of .05 and power of .90, resulting in 20 subjects per group.

Descriptive statistics was performed with mean and standard deviation for continuous data, and median and range for ordinal data. Inferential statistics comparing ACL and ACLR values were performed with Student's paired t-test or Wilcoxon test, and comparing the ACL or ACLR with the control group with Student's t-test or Mann-Whitney U-test. We considered the level of significance $p < .05$.

Results

The groups were similar regarding to age. Body composition evaluation showed no significant differences in the ACL group comparing the preoperative with the postoperative moments, neither in the comparison with the control group (Table 1).

Table 1. Baseline and body composition measurements of athletes with ACL injury, after ACLR and controls.

	ACL	ACLR	Control	ACL vs ACLR	ACL vs control	ACLR vs control
					p value	
Age, years median (range)	21 (18–28)	-	20.5 (18–34)	-	.99	-
Weight (kg)	79.2 ± 10.1	79.3 ± 8.9	74.8 ± 6.2	.20	.12	.07
Height (m)	1.82 ± 0.08	-	1.79 ± 0.07	-	.13	-
Fat-free mass (kg)	67.2 ± 8.0	67.3 ± 6.8	65.2 ± 6.1	.34	.38	.32
Body fat (%)	14.7 ± 3.7	14.9 ± 5.4	12.8 ± 4.0	.76	.12	.16
Muscle mass (kg)	38.4 ± 4.8	38.4 ± 4.1	37.3 ± 3.6	.36	.43	.37
BMI	23.7 ± 2.0	24.0 ± 2.0	23.4 ± 1.8	.11	.68	.34

BMI: body mass index

https://doi.org/10.1371/journal.pone.0194432.t001

VO_{2max} in the control group was 56.9 ± 4.2 mL/kg/min. In the athletes with ACL injury VO_{2max} was 45.2 ± 4.3 and after ACLR increased to 48.9 ± 3.8. All comparisons were statistically significant ($p < .001$). VT_1 and VT_2 were also lower after ACLR than in the control group, but significantly higher than before surgery (Table 2). Average ACL injured and ACLR VO_{2max} values were 20% and 14% lower than controls, respectively. All comparisons were statistically significant. In the ACL injured athletes, the correlation between time from injury and Vo_{2max} was not significant, neither at the pre-operative period ($r_s = .064$, $p = .79$), nor at the post-operative period ($r_s = -.24$, $p = .3$).

Running speed at VO_{2max}, at VT_1 and at VT_2 were significantly lower in the ACL group than in the control group (Table 2). It increased after ACLR, although still lower than controls. All comparisons were statistically significant, except for the running speed at VT_1 comparing the ACLR with the control group. The percentage of respective VO_{2max} at which the ventilatory thresholds occurred were similar in all situations, except for the VT_1 comparing ACLR and controls.

Median knee function score IKDC improved from 59.2 to 90.8 ($p < .001$), compared to 100 in the control group ($p < .001$) and median Lysholm score improved from 80 to 95 ($p < .001$), compared to 100 in the control group ($p = .03$) (Table 3). Average extension peak torque deficit at 60°s after ACLR was 15.7%. The comparison between ACLR and the control group showed a statistically significant difference in the extensor and flexor peak torque normalized by body mass and peak torque deficit.

Discussion

ACL tears are severe injuries, and may impact the career of a professional soccer player.[26] Surgical treatment leads to a phase of reduced activity and physical deconditioning.[13] However, few studies addressed the issue of aerobic fitness after ACLR in soccer players. In this study, we showed that VO_{2max} is highly reduced in ACL injured professional soccer players and, although it shows an improvement six months after ACLR and rehabilitation, it is still significantly lower than we observed in players of the same level.

Table 2. VO_{2max} and ventilatory thresholds before and after ACLR and in the control group.

	ACL	ACLR	Control	ACL vs ACLR	ACL vs control	ACLR vs control
				p value [IC 95% of the difference]		
VO_{2max} (mL/kg/min)	45.2 ± 4.3	48.9 ± 3.8	56.9 ± 4.2	< .001 [-5.6, -2.0]	< .001 [8.9, 14.4]	< .001 [5.4, 10.5]
vVO_{2max} (km/h)	14.4 (10.8–19.2)	15.6 (13.2–19.2)	16.8 (15.6–19.2)	.007 [1.8, 3.8]	< .001 [1.8, 3.8]	< .001 [0.9, 2.7]
VT_2 (mL/kg/min)	38.3 ± 4.1	41.4 ± 4.5	49.1 ± 3.6	.008 [-5.5, -0.9]	< .001 [8.3, 13.2]	< .001 [5.0, 10.2]
$\%VO_{2max}VT_2$	85 ± 6	85 ± 7	86 ± 4	.92 [-4.8, 5.3]	.39 [-1.9, 4.9]	.36 [-2.1, 5.6]
vVT_2 (km/h)	10.8 (9.6–13.2)	12 (10.8–13.2)	13.2 (12.0–15.6)	.006 [1.7, 2.9]	< .001 [1.7, 2.9]	< .001 [1.1, 2.3]
VT_1 (mL/kg/min)	30.3 ± 5.1	34.3 ± 3.5	37.2 ± 3.7	.006 [-6.7, -1.3]	< .001 [4.1, 9.8]	.015 [0.6, 5.3]
$\%VO_{2max}VT_1$	67 ± 8	70 ± 7	65 ± 6	.22 [-9, 2.2]	.61 [-6.1, 3.6]	.04 [-9.1, -0.2]
vVT_1 (km·h⁻¹)	9.6 (7.2–10.8)	9.6 (8.4–10.8)	9.6 (9.6–12.0)	.025 [0.5, 1.5]	< .001 [0.5, 1.5]	.095 [-0.4, 0.9]

VO_{2max}: maximum oxygen uptake; VT_1 and VT_2: first and second ventilatory thresholds

$\%VO_{2max}VT_1$ and $\%VO_{2max}VT_2$: percentage of VO_{2max} corresponding to VT_1 and VT_2

vVO_{2max}, vVT_1 and vVT_2: running speeds at VO_{2max}, VT_1 and VT_2, median (range). All other values represent mean ± standard deviation

Table 3. Self-reported knee function questionnaire results, median (range), and isokinetic knee extensors and flexors strength at 60 º/s, normalized by body mass (mean and standard deviation).

	ACL	ACLR	Control	ACL vs ACLR	ACL vs control	ACLR vs control
					p value	
IKDC	59.2 (26.4–90.8)	90.8 (63–100)	100 (86–100)	< .001	< .001	< .001
Lysholm	80 (39–95)	95 (77–100)	100 (90–100)	< .001	< .001	.030
Extension (N.m/Kg)	252.2 ± 60.6	291.3 ± 45.5	358 ± 44.2	.008	< .001	< .001
Extension PT deficit (%)	21.5 ± 18.6	15.7 ± 13.2	3.1 ± 13.9	.630	< .001	< .001
Flexion (N.m/Kg)	151.2 ± 34.3	166.1 ± 30.9	190.5 ± 18.5	.023	< .001	.005
Flexion PT deficit (%)	7.2 ± 17.0	10.7 ± 14.6	2.0 ± 8.0	.410	.231	.026

IKDC: International Knee Documentation Committee Subjective Knee Evaluation Form; PT deficit: peak torque deficit

https://doi.org/10.1371/journal.pone.0194432.t003

VO_{2max} is one of the most important parameters for endurance performance, and has been extensively assessed among soccer players, [8,11,25,27] although not after ACLR. Soccer demands a high level of aerobic fitness to be successfully played at a professional level. A VO_{2max} of 60 ml/kg/min has been suggested as the minimum fitness requirement to play at the men's professional level.[25] Data from 1545 Norwegian male soccer players indicate that VO_{2max} values from 62 to 64 ml/kg/min fulfill the demands in men's professional soccer, although players from third to fifth division teams demonstrated an average 2 mL/kg/min lower VO_{2max} than the higher divisions players.[12] In our study, control group athletes showed a 56.8 ± 4.2 mL/kg/min VO_{2max}. These VO_{2max} values were significantly higher than the values we found six months after ACLR, 48.9 ± 3.8 mL/kg/min, and higher than we found before surgery, 45.2 ± 4.3, which represents a 20% lower VO_{2max} when compared to the control group. For comparison purposes, the age-related decline in VO_{2max} is reported at 10% per decade.[28] Obviously, endurance is not the only factor related to soccer performance, and technical and tactical skills may make up for a fitness deficiency, but some studies show that the VO_{2max} is directly related to soccer performance. [24] Also, it has been demonstrated that VO_{2max} is an independent predictor of injury in soccer players. [29]

VO_{2max} may be affected by the lung capacity, cardiac output and O_2 carrying capacity of the blood, termed central factors, and by the skeletal muscle efficiency, termed peripheral factor. Accordingly, to the equation of Fick, VO_2 = cardiac output x arteriovenous oxygen difference. Cardiac output is reduced after knee surgery in soccer players.[13] Skeletal muscle O_2 extraction is also reduced with the reduction in muscle power and strength. Although both factors are probably involved, previous studies show that central factors are viewed as the main limiting factor for VO_{2max}.[10]

VT_1 represents the anaerobic threshold measured by ventilatory changes [11,30] and is a predictor of endurance capacity considered more sensitive to the training status than VO_{2max}.[31] Because of the game duration, soccer is mainly dependent upon aerobic metabolism, but soccer matches show periods and situations of high intensity where the anaerobic metabolism prevails.[8] The reduction in VT_1 can be explained by a worse ATP turnover through the aerobic pathway and rapid involvement of the glycolytic pathway.[32] The VT_2, or respiratory compensation point, is related to the acid-basis regulation and the efficiency of the buffer system to keep pH in the blood and peripheral muscle. Rehabilitation exercises improves the buffer system in the muscle[33] explaining the improvement in VT_2 after rehabilitation. The improvement in VT_1 and VT_2 observed in ACL patients after reconstruction indicates a better

physical conditioning after surgery than before. However, all results were lower than observed in the control group.

There is a possibility that the poor aerobic fitness observed in the ACL injured players contributed to the injury itself. To evaluate this hypothesis, we would need the baseline results of these athletes. This is an interesting field for research, and some papers are finding results to corroborate this. [29] In this case, it reinforces the need to evaluate and improve the aerobic fitness of professional soccer players before they return to play, to avoid other injuries.

ACL surgery is considered effective in restoring knee function, and also to allow the participation in high demand activities such as professional soccer.[34,35] However, the concept of studying athletic performance on return to sport from ACL reconstruction is relatively new and under-researched.[36] We chose the six-month follow-up period to perform postoperative evaluation because this is usually the period we are considering to allow the athlete to return to play.[6] The patients performed the test at six months, independently of other criteria for return to play. In this study we found a postoperative median IKDC subjective score of 90.8 and median Lysholm score of 95, which are considered excellent results.[20,21]. Also, we observed a postoperative quadriceps strength deficit of 15.7%, which is in accordance with the literature.[37,38] Moreover, body composition measurements in the ACL athletes and after ACLR showed no significant differences compared to controls. Despite these satisfactory results[5,6], recent evidence show that up to 45% of athletes do not return to their previous level of sports activity.[7] The deficit in VO_{2max} observed in this study may be one additional factor that help explain the discrepancy between knee function recovery and sports performance after ACL reconstruction. [13–15,39] At the best of our knowledge, no previous study addressed the VO_{2max} after ACLR rehabilitation as the primary outcome measure. [5,15]

This is not a randomized study, and therefore many forms of bias, including selection bias, may occur. We tried to avoid this by choosing a control group that matched our patients, all of them being professional soccer players at the second and third state divisions. The control group was tested only once, during their competitive season, and were not prospectively followed, as the ACL injured athletes. Since that no intervention was performed in the control group, we did not expect a significant time effect during the six months in this group, although it might occur. Our baseline and anthropometric data show that the samples are comparable in terms of age and body composition. Second, one may argue that the treadmill test could be jeopardized by the knee condition of the individual, resulting in a VO_{2max} not representative of the actual aerobic fitness. However, during the tests, all athletes reached the criteria for a maximal test, defined in the methods session. Only one patient, with a bucket-handle meniscal injury, was unable to conclude the test because of knee symptoms. Moreover, it is known that the VO_{2max} obtained with cycle ergometer and bicycle protocols are lower than those obtained with treadmill testing.[8] Also, soccer players should use the treadmill as this mode of exercise is closer to their specific activity. Third, the three-month time span between injury and surgery may be considered too long, mainly in professional players. This occurred because of the characteristic of our public health system, although we don't think this period is excessive. Also, it allowed us to evaluate the effect of ACL injury on deconditioning prior to ACLR.

Therefore, VO_{2max} is significantly reduced in soccer players with ACL injury, and six months of standard rehabilitation was not enough to restore aerobic function after ACL reconstruction. More attention should be paid to aerobic conditioning in professional soccer players at return to sports after ACLR, and aerobic function evaluation should be considered in high level athletes. These findings should have implications for the routine rehabilitation after ACL reconstruction in soccer players. Future research should focus on strategies to prevent aerobic function deconditioning in athletes with ACL injury before and after surgery.

Conclusions

We conclude that the aerobic capacity of professional soccer players six months after ACL reconstruction, measured by VO_{2max}, ventilatory thresholds and running speeds, are significantly lower than in the control group athletes, although higher than before surgery. The knee function scores showed a significant improvement after surgery, and body composition evaluations were not significantly different.

Supporting information

S1 File. VO_{2max} and ventilatory thresholds of ACL injured athletes and healthy controls. (XLSX)

S2 File. Body composition evaluation of ACL injured athletes and healthy controls. (XLSX)

Author Contributions

Conceptualization: Adriano Marques de Almeida, Paulo Roberto Santos Silva, André Pedrinelli, Arnaldo J. Hernandez.

Data curation: Paulo Roberto Santos Silva, Arnaldo J. Hernandez.

Formal analysis: Adriano Marques de Almeida, Paulo Roberto Santos Silva.

Investigation: Adriano Marques de Almeida, Paulo Roberto Santos Silva.

Methodology: Adriano Marques de Almeida, Paulo Roberto Santos Silva, André Pedrinelli, Arnaldo J. Hernandez.

Project administration: Adriano Marques de Almeida.

Resources: Paulo Roberto Santos Silva, André Pedrinelli, Arnaldo J. Hernandez.

Supervision: Adriano Marques de Almeida, André Pedrinelli, Arnaldo J. Hernandez.

Validation: Paulo Roberto Santos Silva, André Pedrinelli.

Visualization: Adriano Marques de Almeida, André Pedrinelli, Arnaldo J. Hernandez.

Writing – original draft: Adriano Marques de Almeida.

Writing – review & editing: Adriano Marques de Almeida, Paulo Roberto Santos Silva, André Pedrinelli, Arnaldo J. Hernandez.

References

1. Chomiak J, Junge A, Peterson L, Dvorak J. Severe Injuries in Football Players Influencing Factors. The American Journal of Sports Medicine. American Orthopaedic Society for Sports Medicine; 2000; 28: S–58–S–68. https://doi.org/10.1177/28.suppl_5.S-58

2. Myer GD, Paterno MV, Ford KR, Quatman CE, Hewett TE. Rehabilitation after anterior cruciate ligament reconstruction: criteria-based progression through the return-to-sport phase. J Orthop Sports Phys Ther. 2006; 36: 385–402. https://doi.org/10.2519/jospt.2006.2222 PMID: 16776488

3. Warner SJ, Smith MV, Wright RW, Matava MJ, Brophy RH. Sport-specific outcomes after anterior cruciate ligament reconstruction. Arthroscopy. 2011; 27: 1129–1134. https://doi.org/10.1016/j.arthro.2011.02.022 PMID: 21664792

4. Zaffagnini S, Grassi A, Marcheggiani Muccioli GM, Tsapralis K, Ricci M, Bragonzoni L, et al. Return to sport after anterior cruciate ligament reconstruction in professional soccer players. Knee. 2014; 21: 731–735. https://doi.org/10.1016/j.knee.2014.02.005 PMID: 24593869

5. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. Br J Sports Med. BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine; 2016; 50: 946–951. https://doi.org/10.1136/bjsports-2015-095908 PMID: 27215935

6. Barber-Westin SD, Noyes FR. Factors Used to Determine Return to Unrestricted Sports Activities After Anterior Cruciate Ligament Reconstruction. Arthroscopy. Elsevier Inc; 2011; 27: 1697–1705. https://doi.org/10.1016/j.arthro.2011.09.009 PMID: 22137326

7. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. Br J Sports Med. BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine; 2014; 48: 1543–1552. https://doi.org/10.1136/bjsports-2013-093398 PMID: 25157180

8. Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: an update. Sports Med. 2005; 35: 501–536. PMID: 15974635

9. Castagna C, Abt G, D'Ottavio S. Physiological aspects of soccer refereeing performance and training. Sports Med. 2007; 37: 625–646. PMID: 17595157

10. Bassett DRJ, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc. 2000; 32: 70–84. PMID: 10647532

11. Santos-Silva PR, Fonseca AJ, Castro AW de, Greve JMD, Hernandez AJ. Reproducibility of maximum aerobic power (VO2max) among soccer players using a modified heck protocol. Clinics. SciELO Brasil; 2007; 62: 391–396. PMID: 17823700

12. Tonnessen E, Hem E, Leirstein S, Haugen T, Seiler S. Maximal aerobic power characteristics of male professional soccer players, 1989–2012. Int J Sports Physiol Perform. 2013; 8: 323–329. PMID: 23118070

13. Olivier N, Legrand R, Rogez J, Berthoin S, Weissland T. Effects of knee surgery on cardiac function in soccer players. Am J Phys Med Rehabil. LWW; 2007; 86: 45–49. PMID: 17304688

14. Olivier N, Weissland T, Legrand R, Berthoin S, Rogez J, Thevenon A, et al. The effect of a one-leg cycling aerobic training program during the rehabilitation period in soccer players with anterior cruciate ligament reconstruction. Clin J Sport Med. LWW; 2010; 20: 28–33. https://doi.org/10.1097/JSM.0b013e3181c967b8 PMID: 20051731

15. Villa Della S, Boldrini L, Ricci M, Danelon F, Snyder-Mackler L, Nanni G, et al. Clinical Outcomes and Return-to-Sports Participation of 50 Soccer Players After Anterior Cruciate Ligament Reconstruction Through a Sport-Specific Rehabilitation Protocol. Sports Health. 2012; 4: 17–24. https://doi.org/10.1177/1941738111417564 PMID: 23016064

16. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001; 37: 153–156. PMID: 11153730

17. Bhambhani Y, Singh M. Ventilatory thresholds during a graded exercise test. Respiration. 1985; 47: 120–128. https://doi.org/10.1159/000194758 PMID: 4001567

18. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Manuel Gómez J, et al. Bioelectrical impedance analysis—part II: utilization in clinical practice. Clinical Nutrition. 2004; 23: 1430–1453. https://doi.org/10.1016/j.clnu.2004.09.012 PMID: 15556267

19. Bogdanis GC, Kalapotharakos VI. Knee Extension Strength and Hamstrings-to-Quadriceps Imbalances in Elite Soccer Players. Int J Sports Med. 2015; 95: 119–124. https://doi.org/10.1055/s-0035-1559686

20. Peccin MS, Ciconelli R, Cohen M. Questionário específico para sintomas do joelho "Lysholm Knee Scoring Scale": tradução e validação para a língua portuguesa. Acta ortop bras. scielo; 2006; 14: 268–272.

21. Metsavaht L, Leporace G, Riberto M, de Mello Sposito MM, Batista LA. Translation and cross-cultural adaptation of the Brazilian version of the International Knee Documentation Committee Subjective Knee Form: validity and reproducibility. The American Journal of Sports Medicine. American Orthopaedic Society for Sports Medicine; 2010; 38: 1894–1899. https://doi.org/10.1177/0363546510365314 PMID: 20472755

22. Fernandes TL, Fregni F, Weaver K, Pedrinelli A, Camanho GL, Hernandez AJ. The influence of femoral tunnel position in single-bundle ACL reconstruction on functional outcomes and return to sports. Knee

Surgery, Sports Traumatology, Arthroscopy. 2014; 22: 97–103. https://doi.org/10.1007/s00167-012-2288-8 PMID: 23132410

23. Plaweski S, Rossi J, Merloz P. Anterior cruciate ligament reconstruction: assessment of the hamstring autograft femoral fixation using the EndoButton CL. Orthop Traumatol Surg Res. 2009; 95: 606–613. https://doi.org/10.1016/j.otsr.2009.09.011 PMID: 19944664

24. Helgerud J, Engen LC, Wisloff U, Hoff J. Aerobic endurance training improves soccer performance. Med Sci Sports Exerc. 2001; 33: 1925–1931. PMID: 11689745

25. Castagna C, Impellizzeri FM, Chaouachi A, Manzi V. Preseason variations in aerobic fitness and performance in elite-standard soccer players: a team study. J Strength Cond Res. 2013; 27: 2959–2965. https://doi.org/10.1519/JSC.0b013e31828d61a8 PMID: 23442266

26. Walden M, Hagglund M, Magnusson H, Ekstrand J. ACL injuries in men's professional football: a 15-year prospective study on time trends and return-to-play rates reveals only 65% of players still play at the top level 3 years after ACL rupture. Br J Sports Med. 2016; 50: 744–750. https://doi.org/10.1136/bjsports-2015-095952 PMID: 27034129

27. Zinner C, Sperlich B, Wahl P, Mester J. Classification of selected cardiopulmonary variables of elite athletes of different age, gender, and disciplines during incremental exercise testing. Springerplus. 6 ed. Springer International Publishing; 2015; 4: 544. https://doi.org/10.1186/s40064-015-1341-8 PMID: 26413450

28. Hawkins SA, Wiswell RA. Rate and Mechanism of Maximal Oxygen Consumption Decline with Aging. Sports Med. Springer International Publishing; 2003; 33: 877–888. https://doi.org/10.2165/00007256-200333120-00002 PMID: 12974656

29. Watson A, Brindle J, Brickson S, Allee T, Sanfilippo J. Preseason Aerobic Capacity Is an Independent Predictor of In-Season Injury in Collegiate Soccer Players. Clin J Sport Med. 2016. https://doi.org/10.1097/JSM.0000000000000331 PMID: 27347859

30. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol Respir Environ Exerc Physiol. 1986; 60: 2020–2027.

31. Edwards AM, Clark N, Macfadyen AM. Lactate and Ventilatory Thresholds Reflect the Training Status of Professional Soccer Players Where Maximum Aerobic Power is Unchanged. J Sports Sci Med. 2003; 2: 23–29. PMID: 24616606

32. Vago P, Mercier J, Ramonatxo M, Prefaut CH. Is ventilatory anaerobic threshold a good index of endurance capacity? Int J Sports Med. 1987; 8: 190–195. https://doi.org/10.1055/s-2008-1025654 PMID: 3623780

33. Sahlin K. Muscle energetics during explosive activities and potential effects of nutrition and training. Sports Med. Springer; 2014; 44: 167–173.

34. Maletis GB, Cameron SL, Tengan JJ, Burchette RJ. A prospective randomized study of anterior cruciate ligament reconstruction: a comparison of patellar tendon and quadruple-strand semitendinosus/gracilis tendons fixed with bioabsorbable interference screws. The American Journal of Sports Medicine. 2007; 35: 384–394. https://doi.org/10.1177/0363546506294361 PMID: 17218661

35. Ekstrand J. A 94% return to elite level football after ACL surgery: a proof of possibilities with optimal caretaking or a sign of knee abuse? Knee Surg Sports Traumatol Arthrosc. Springer-Verlag; 2011; 19: 1–2. https://doi.org/10.1007/s00167-010-1300-4 PMID: 21052981

36. Lai CCH, Ardern CL, Feller JA, Webster KE. Eighty-three per cent of elite athletes return to preinjury sport after anterior cruciate ligament reconstruction: a systematic review with meta-analysis of return to sport rates, graft rupture rates and performance outcomes. Br J Sports Med. 2017;: bjsports–2016–096836–11. https://doi.org/10.1136/bjsports-2016-096836 PMID: 28223305

37. Dauty M, Tortellier L, Rochcongar P. Isokinetic and anterior cruciate ligament reconstruction with hamstrings or patella tendon graft: analysis of literature. Int J Sports Med. 2005; 26: 599–606. https://doi.org/10.1055/s-2004-821342 PMID: 16195995

38. Czaplicki A, Jarocka M, Walawski J. Isokinetic Identification of Knee Joint Torques before and after Anterior Cruciate Ligament Reconstruction. PLoS One. 2015; 10: e0144283. https://doi.org/10.1371/journal.pone.0144283 PMID: 26646385

39. Bizzini M, Silvers HJ. Return to competitive football after major knee surgery: more questions than answers? J Sports Sci. 2014; 32: 1209–1216. https://doi.org/10.1080/02640414.2014.909603 PMID: 24783969