VERTICAL JUMP CHARACTERISTICS FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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The purpose of this study was to compare two-legged countermovement vertical jump characteristics between operated and non-operated lower limbs of twelve recreational athletes who had undergone unilateral ACL surgical reconstruction. A control group of eight uninjured athletes was employed. Bilateral vertical ground reaction forces, joint angles, moments and powers patterns were measured and statistically analysed. The examination of the angular kinematics revealed for the injured limb a significant reduction of the knee and ankle extension angles at the take off and an ankle ROM reduction. Examining peak moments and powers the injured knee exhibited significant lower values. The reduction of the knee peak power seems to be compensated in most of the subjects by an increase of the omolateral ankle peak power.

KEY WORDS: optoelectronic system, bilateral asymmetries, soccer players

INTRODUCTION: Some changes in contractile capacity, and hence in the production of force and power, are the inevitable outcome of any musculo skeletal injury. Even a relatively short time of inactivity are likely to result in a significant reduction of the athlete's functional capacity and in several dimensions of 'fitness', such as strength, flexibility, endurance, and co-ordination.

Anterior cruciate ligament (ACL) injuries are the most common ligament injury of the knee both recreational and competitive athletes (Johnson, 1983). Given the key role of this ligament in knee stability and functioning it is common for orthopaedic surgeons to recommend surgical reconstruction and an intensive rehabilitation program for patients with a torn ACL.

While this procedure provides some increase in knee stability, some biomechanical analyses of rehabilitated individuals with ACL reconstruction have demonstrated several compensatory adaptations of these people during activities such as walking, jogging and stair climbing (Andriacci, 1990; Kowalk, Duncan, and McCue 111, 1997). In light of these findings it seems important to assess whether these adaptations would translate to natural sport movements like jumping which requires large joint excursions and torques.

Vertical jump is a complex ballistic movement in which the joint muscles of the lower limbs collectively operate to produce patterned movements by means of multijoint coordination and energy, which is released, stored and transferred. This exercise, showing the subjects ability to integrate muscle contractions into an efficient quick movement, has thus several advantages compared to isokinetic dynamometers usually employed to measure the force and power of the lower limb isolated muscle groups.

This study compared two-legged counter movement vertical jump characteristics between operated and non-operated lower limbs of a group of recreational athletes who had undergone unilateral ACL surgical reconstruction. The final aim was to develop procedures to determine not only the static, anatomic-pathological consequences of the ACL injury, but also its dynamic effects on neuromuscular function and motor co-ordination.

METHODS: Twelve subjects (age 27±5 yr., height 176±6 cm, body mass 74±7 kg) who had suffered a unilateral ACL injury within the 1-yr period prior to the study and eight uninjured subjects (age 28±4 yr., height 174±5 cm, body mass 72±7 kg) who served as a reference group were recruited for this study. All were semi-professional soccer players.

The injured athletes had arthroscopically assisted, bone-patella-bone reconstruction using the central one-third of the patellar tendon. A six month-long standard rehabilitation procedure was employed. At the time of the laboratory testing all the injured subjects have resumed their athletic activity with the same regularity as before injury and none of them reported any particular problem or functional restriction following recovery.

Ten retroreflective hemispherical markers (12 mm in diameter) were placed on the iliac crests, centre of the greater trochanters, the lateral femoral condyles, lower edge of lateral malleoli, lateral side of the 5th metatarsal head (on the shoes).

After 20 minutes of standard warm up in which the athletes became familiar with the experimental setting, each subject performed four series of five double-legged maximum-height countermovement vertical jumps while keeping their hands behind their back in order to minimise the influence of the arms and trunk inertia to the movement. No attempts were made to standardise the starting position, the amplitude, and the rate of the countermovement. Each foot was placed on a force platform. Between the jumps and the series, the subjects rested 2 min. and 5 min. to avoid fatigue, respectively.

At a sampling frequency of 100 Hz, the 3D coordinates of each marker glued onto the subject's skin were estimated by an ELITE (B.T.S. srl, Milan, Italy) automatic motion analyser by means of four TV cameras paired on the two sides of the subjects to allow a double side 3D analysis. Simultaneously, at a sampling frequency of 500 Hz, vertical foot-ground reaction forces (VGRFs) of the right and left limbs were measured by a force-measuring system consisting of two Kistler 928 1B piezoelectric platforms collaterally installed for adjacent positioning of both feet during the push off.

The internal joint moments and powers were estimated by using special software using anthropometric, kinematic and kinetic data as input. All trials were normalised over the movement phase (from the start of the countermovement to the instant the toes lost contact with the force platform). Cubic spline interpolation was applied to the original data points to obtain 100 samples per trial independent from the actual movement duration. In addition, the height of the jump was computed from flight time, by multiplying the square of the flight duration by 1.266. The individual percentage asymmetry (ASY%) between right/ left (for the uninjured group) and Normal/ACL (for the injured group) limbs, for each of the kinetic parameter, were calculated. The Wilcoxon signed rank test was used to assess whether or not significant differences in the selected parameters, exist. The alpha level of significant differences was set at the $p<0.05$.

RESULTS: The mean jumping height values were 35.9 $\pm$ 6 cm, and 35.2 $\pm$ 7 cm for the healthy and pathological subjects, respectively.

Two typical VGRF patterns were found. One was characterised by an initial decay of the force, followed by two peaks with a relative minimum, while the other showed only one maximum in the push phase. No significant difference in the occurrence of the two patterns between the groups was found.

In the injured subjects, considering averaged VGRF amplitude and timing parameters, no significant differences have been found between the operated and non-operated limbs. The injured subjects showed a significant lower total movement duration, a trend for a higher first minimum, and lower absolute maximum. It was found that the pathological subjects reached the first minimum earlier, have a longer propulsive phase and need more time to pass from the countermovement minimum to the first maximum.

For the reference and patient group, bilateral comparisons for some selected kinematic and kinetic values are reported in Table 1. In the injured group, the examination of the angular kinematic revealed for the operated limb a significant reduction of the knee and ankle extension angles at the take off and a significant reduction of the knee angular excursion. Examining peak moments and powers the injured knee exhibited significant lower values. To note the higher power values found at the ankle of the operated limb. Typical joint moment and power profiles for the operated and nonoperated limb of one representative subject are shown in Figure 1.

A trend for a major joint angle extension at the take off was observed in the healthy group. Looking at the kinetic the only significant group differences were found at the knee with the healthy subjects characterised by higher values.

Table 1 Average Group Values for Some Selected Kinematic and Kinetic Values

		Uninjured			Injured		
		Left	Right	ASY %	Norm	ACL	ASY %
	Hip	17(10)	20(12)	15	20(8)	24(8)	16.7
Take off Angle (degrees)	Knee	8(9)	8(7)	0	10(5)	15(6)	33.3*
	Ankle	29(9)	27(8)	7	31(5)	37(7)	16.2*
	Hip	50(13)	47(12)	6	51(15)	49(14)	4
Angular Excursion[a] (degrees)	Knee	70(9)	73(10)	4.1	67(8)	59(8)	12*
	Ankle	51(7)	53(9)	3.8	56(6)	54(8)	3.6
	Hip	139 (36)	127 (22)	8.6	135 (40)	123 (36)	8.9
Moment (N.m)	Knee	159 (32)	169 (28)	5.6	139 (32)	110 (36)	20.9*
	Ankle	99 (15)	104 (18)	4.8	109 (22)	113 (24)	3.5
	Hip	394 (92)	414 (118)	4.8	415 (96)	394 (114)	5.1
Power Watt	Knee	765 (130)	792 (122)	3.4	650 (109)	477 (124)	26.6*

[a]Angular excursion values from the maximum joint flexion to the take off. *Significant asymmetries

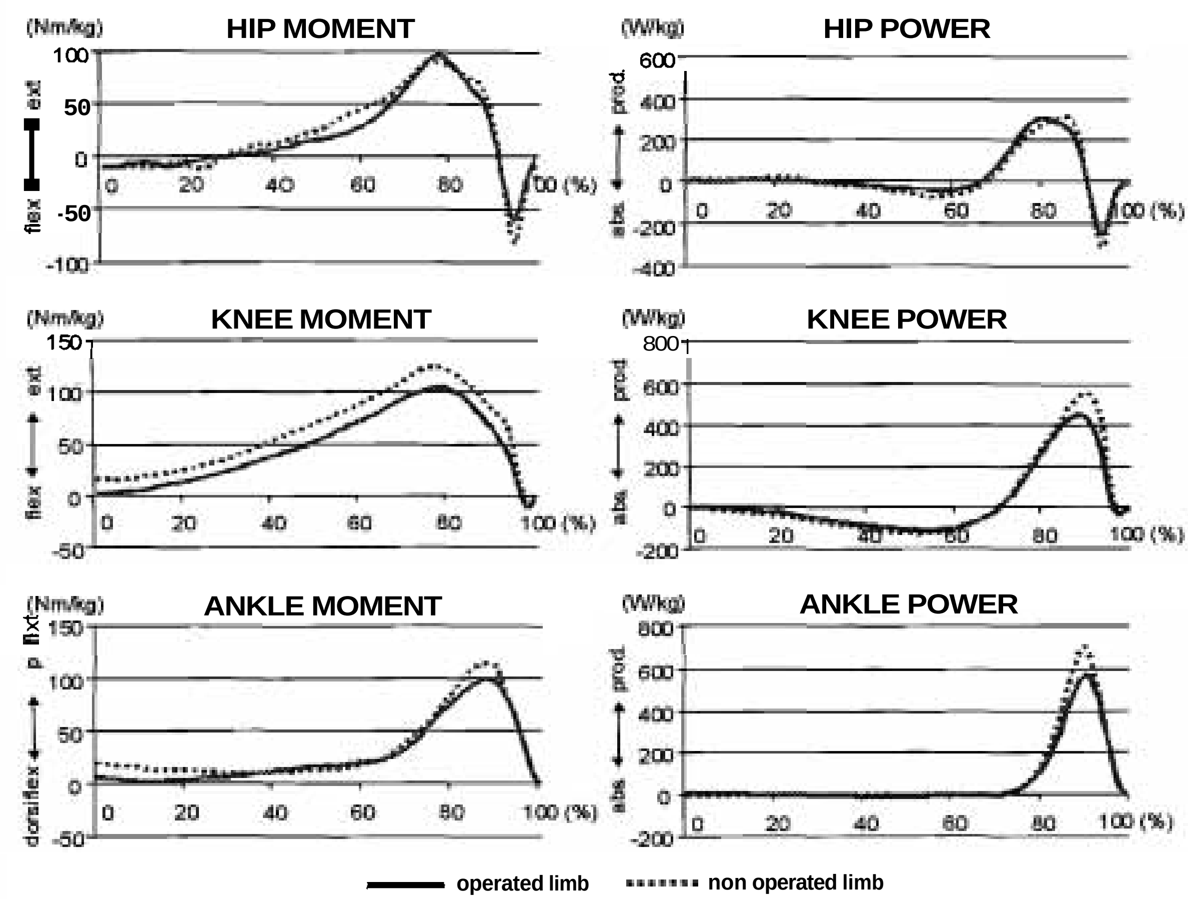

Figure 1 - Exemplar Joint Moment and Power Profiles for the Operated and non-Operated Limb of One Representative Subject

DISCUSSION: Logically, bilateral vertical jump should be a symmetrical activity, with each leg making an equal contribution. As highlighted in the results section significant asymmetries were found between the two body sides of post rehabilitated ACL operated subjects. It should be considered that these subjects were considered completely recovered by physicians and coaches and displayed a jumping height similar to what was observed in the healthy group. Even in vertical jump, a distinctive feature of the human motor system seems to be exploited, namely the potential to execute the same motor task through different combinations of muscle forces or of motor equivalent actions.
In evaluating the observed asymmetries it would be important to establish whether this differences are related to the injury and/or surgical intervention, or possibly could have been present prior to injury. Because preinjury data are rarely available for this type of research, it was considered necessary to evaluate an uninjured subject group to establish an estimate for the magnitude of the asymmetries in a normal population.
One of the main findings was the reduced peak power at the operated knee joint. This adaptation could be interpreted as a subconscious desire to reduce the net quadriceps force required during jumping. This was similar to what was found in walking, running and stair climbing. Although this hypothesis has not been directly tested, it is the consensus that these adaptations may be beneficial to ACL operated subjects because they reduce anterior displacement of the tibia relative to the femur. This would reduce stress on the knee joint while enabling the subjects to perform the desired movement.
The reduction of the knee peak power seems to be compensated in most of the subjects by an increase of the omolateral and to less extent of the controlateral ankle peak power. The intact ankles therefore assisted the injured knee during the crucial phase of the push phase.
Variations in the time between surgery and assessment, in rehabilitative protocols, compliance with rehabilitation and in patient characteristics may be confounding factors in this study. In addition, there was considerable variability in the observed asymmetries among individuals both injured and uninjured group. As a consequence the presented group data washes out important intersubject differences and can not be assumed as representative of all the athletes analysed.
In conclusion, even if the generalisability of the present results to all individuals with ACL injury and reconstruction is critical, the test we described allows identifying mechanical and motor differences in a population of athletes. In particular it revealed a difference in VGRFs, kinematic and kinetic traces between pathological and sound limb in a group of subjects after injury. This behavior can only rarely be observed without the aid of a dynamic test as the one described. Future studies should be focused on the long-term adaptation to ACL reconstruction and to contrast different methods of reconstruction.

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