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Compliant surface after ACL reconstruction and its effects on gait

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ABSTRACT. Previous studies of gait analysis in patients following reconstructive anterior cruciate ligament (ACL) surgery have shown changes in kinematics, kinetics and energy patterns in the lower limb. Usually these patients perform complaint surface training during clinical treatment. The purpose of this study was to evaluate the changes in selected gait kinematic parameters following ACL reconstruction while walking on an unstable surface. We tested 16 subjects: eight patients who underwent ACL reconstruction, at four weeks after the surgical intervention; and eight healthy subjects (control group) matched by age and gender. Participants walked at a self-selected comfortable speed on an 8 m-walkway while sagittal plane kinematic data of the principal lower limb joints (hip, knee and ankle) were collected using 60-Hz cameras. We compared the joint angles under three conditions: (A) walking on stable ground, (B) walking on a foam mat (5 cm thick; 33 kg m^{-3} density) and (C) back at the normal ground. Results showed that ACL patients were slower and had smaller range of motion at all joints as compared to the control group under all conditions; however the repeated exposure to unstable surface may help changes in such patients. Further investigation is necessary to expand our understanding and may improve the development of more effective rehabilitation treatments.

Keywords: anterior cruciate ligament, kinematics, gait, rehabilitation.

Superfície instável após reconstrução do LCA e seu efeito na marcha

RESUMO. Estudos avaliando a marcha em pacientes com reconstrução do ligamento cruzado anterior (LCA) mostram diferenças em parâmetros cinemáticos, cinéticos e energéticos. É comum para estes pacientes realizar treinamento de marcha em superfícies instáveis durante o tratamento clinico. O objetivo deste estudo foi avaliar as mudanças em parâmetros cinemáticos específicos da marcha após a cirurgia de reconstrução do LCA quando caminhando em superfície instável. Foram testados 16 indivíduos: oito pacientes que realizaram a cirurgia de reconstrução do LCA com quatro semanas após a cirurgia; e oito indivíduos saudáveis (grupo controle) pareados por idade e gênero. Os participantes caminharam em velocidade confortável numa plataforma de 8 m enquanto os dados cinemáticos do plano sagital das articulações do membro inferior (quadril, joelho e tornozelo) eram obtidos com câmeras de 60 Hz. Foram comparados os ângulos articulares em três diferentes condições: (A) caminhando na superfície estável, (B) caminhando num colchão (5 cm de espessura e densidade de 33 kg m^{-3}), e (C) de volta na superfície estável. Os resultados mostraram que os pacientes andaram mais devagar e apresentaram maior amplitude de movimento quando comparados ao grupo controle em todas as condições testadas, entretanto a exposição repetida a instabilidade pode auxiliar na promoção de mudanças neste tipo de paciente. Novos estudos são necessários para expandir nosso entendimento e talvez melhore o desenvolvimento de técnicas de reabilitação mais efetivas.

Palavras-chave: ligamento cruzado anterior, cinemática, marcha, reabilitação.

Introduction

Changes in the gait patterns of subjects following anterior cruciate ligament (ACL) reconstruction have been assessed in a number of studies (BULGHERONI et al., 1997; DEVITA et al., 1997; KNOLL et al., 2004; HART et al., 2009; MORAITI et al., 2009; HART et al., 2010; GAO; ZHENG, 2010; SCANLAN et al., 2010; TSIVGOULIS et al., 2011), all using different techniques. Studies have demonstrated that these individuals walk with different gait parameters in the lower extremity as compared to healthy individuals, such as joint extensor/flexor torques, step length and walking base, joint excursions and muscle activity. These gait patterns may develop as a result of muscle adaptations and neuromuscular reprogramming, possibly in response to pain or instability, to stabilize the knee and to prevent re-injury during gait (FERBER et al., 2002; WEXLER et al., 1998). It is the consensus that these adaptations are beneficial to these individuals because they reduce anterior displacement of the tibia relative to the femur and therefore reduce stress on the knee joint, while they also enable the subjects to perform the desired movement. Also, the agreement of opinion is that the adaptations are caused by subconsciously learned, neuromuscular strategies owing to the injury. However studies evaluating the health-related quality of life after an ACL reconstruction showed that these patients reported good conditions (MANSSON et al., 2011; MÖLLER et al., 2009).

Injuries to the ACL represent a significant portion of the knee injuries sustained by athletes in sport as well as healthy individuals (CERULLI et al., 2003; CHAUDHARI et al., 2008; DELAHUNT et al., 2012). As ACL reconstruction becomes a more predictable and more frequently performed operation, there is an increasing desire on the part of surgeons and patients alike for not only a more rapid return to sporting activities but also to activities of daily living including work and study (FELLER et al., 2001; MÖLLER et al., 2009). The surgical reconstruction is performed to re-establish the mechanical properties of the knee in the hope of returning the patient to an active lifestyle. Most of the advances responsible for allowing the return to pre-injury activity have resulted from improvements in surgical techniques and rehabilitation procedures. A scientifically based and well-designed rehabilitation program plays a vital role in the functional outcome of the ACL-reconstructed individual. Rehabilitation following ACL reconstruction has changed dramatically over the past few decades. The trend toward innovative rehabilitation of the ACL reconstructed knee patient is partly the result of the improved outcomes documented with accelerated rehabilitation compared with more conservative programs. The inclusion of these patients in rehabilitation programs is greatly recommended and produces better functional outcomes, overcoming many of the complications after the ACL reconstruction (prolonged knee stiffness, limitation of complex extension, delay in strength recovery, anterior knee pain) (SHELBOURNE; NITZ, 1992; SHELBOURNE; KLOTZ, 2006).

The ideal situation is one in which the patient with ACL deficiency undergoing surgical reconstruction will ultimately have a result of excellent stability, full range of motion and strength, and normal function. Treatment techniques involving exercises on unstable surfaces may induce compensatory muscle activity and proprioceptive training that could improve knee stability and increase the probability of returning patients to high-level physical activity. Therefore, this study aimed to investigate the changes in selected gait kinematic parameters in the lower limb of ACL-reconstructed individuals during walking on an unstable surface and to compare these findings with an age-matched, injury-free control group.

Material and methods

The study was carried out with a group of 16 participants: eight subjects with ACL-reconstructed (double semitendinosus tendon technique) (five males and three females) and eight healthy subjects with no history of musculoskeletal pathology, matched by age, gender, BMI (body mass index) and activity level. The mean age, body weight, and body height of the ACL-reconstructed subjects were 25.5 year (SD 7.1 year), 61.3 kg (SD 27.1 kg), and 1.68 m (SD 0.1 m), respectively. The ACL-reconstructed subjects were tested on average 32 days (± 6 days) after the surgical intervention. All of them had been advised by their surgeons to resume full weight-bearing at the affected limb, and were taking no medication. No subject reported a history of major back, hip, or ankle pathology/injury or a history of neurologic disease. Ethics approval was obtained by the University's Review Board for Health Sciences Research Involving Human Subjects (0049.0.186.000-06), and all subjects provided written informed consent before testing. This was an exploratory cross-sectional study.

The analysis of gait features was performed using three video cameras for the recording of the kinematic data (60 Hz sampling rate). Eight passive markers were placed at the following positions: (1) on the right greater trochanter; (2) left greater trochanter; (3) right femoral condyle; (4) left femoral condyle; (5) right lateral malleolus; (6) left lateral malleolus; (7) point between the head of the second and third metatarsal (right side); and (8) point between the head of the second and third metatarsal (left side). Each subject was asked to perform five trials of walking at his natural cadence on two different surfaces: (1) on stable ground, and (2) on a foam mat (5 cm thick and 33 kg m^{-3} density). After walking on the unstable surface (foam mat), all subjects went back to the stable ground and walked for another five trials, this was taken as our third testing condition.

The data obtained from the camera recording of the markers allowed the reconstruction of the lower limb segment model, using dedicated gait analysis software (APAS – Ariel Performance Analysis System – Ariel Dynamics Inc). The raw data was high pass filtered to eliminate frequency components below 10 Hz. A single gait cycle (complete stride) was identified, and all the corresponding data sets were then reduced to 100 points. Joint angular positions were calculated at the ankle, knee and hip joints, and the joint range of motion during stride was calculated to compare the two groups among conditions (pre-exposure, exposure and post-exposure). Custom computer algorithms for data analysis were written in IGOR Pro (Wavemetrics Inc.).

Two different groups were defined: (P) ACL-reconstructed subjects, and (C) control subjects. Total joint range of motion was calculated at the ankle (angle between foot and leg segments), knee (angle between leg and thigh segments) and hip (angle between thigh segments and the vertical axis) (see PERRY; BURNFIELD, 2010). The average trend for all variables was computed for each group. Means of individual dependent variables were analyzed using a one-way repeated measures analysis of variance (ANOVA), with group (patients (PG) and controls (CG)) as a between-subject factor, and exposure condition (pre-exposure (PR), exposure (foam mat) (EX), post-exposure (PO)) as the within-subject factor. Subjects were treated as a random factor. For the analysis we compared patients' affected side, and matched with the respective control side. For all analyses, statistical significance was tested using an alpha value of 0.05.

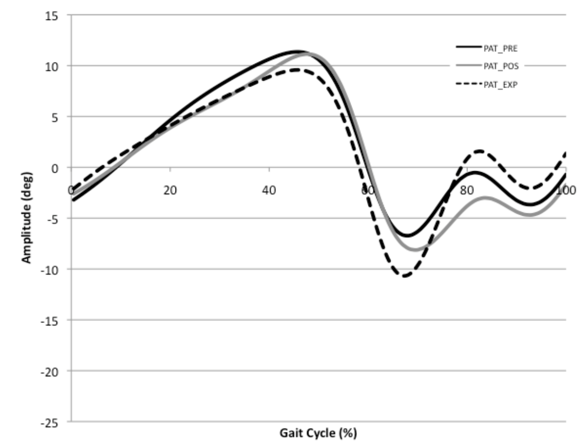
Results and discussion

Stride length was similar between the healthy and patient groups (Table 1); both groups walked approximately 1.23 m to complete a gait cycle. The initial effect of walking on the unstable surface was to increase stride length. In addition, patients were slower than the control subjects in all conditions, although both groups walked faster at the exposure condition (mean = 1.35 m s^{-1} (PG), mean = 1.53 m s^{-1} (CG)). The ANOVA showed a main effect of group and conditions on joint range of motion (Table 1). Patients produced significantly smaller ($p = 0.0266$) range of motion at the knee joint (mean = 34.9°) as compared to the control subjects (mean = 41.7°). Exposure conditions influenced the hip joint ($p < 0.0001$), as the range of motion for the non-exposure conditions (mean = 32.1° (PG), mean = 33.8° (CG)) was smaller than those for the exposure condition (mean = 35.3° (PG), mean = 39.4° (CG)).

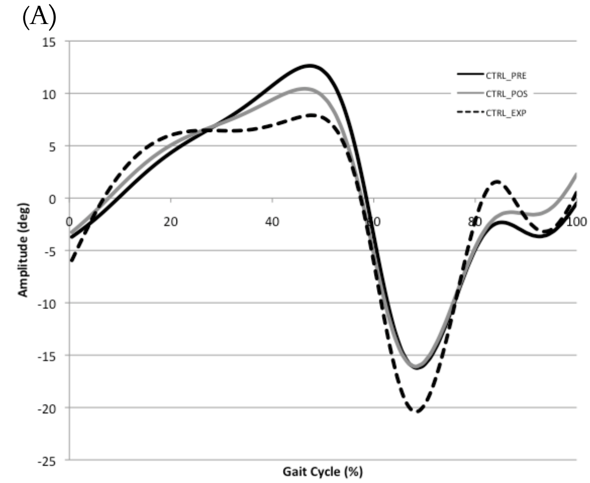
Table 1. Joint range of motion and stride length for patients (PG) and control (CG) subjects under the three conditions tested (Pre-exposure (PR), Exposure (EX) and Post-exposure (PO) (Mean ± SD).

		Ankle (°)	Knee (°)	Hip (°)	Stride length (m)
PR	PG	23.7 ± 6.9	35.0 ± 4.6	32.5 ± 4.3	1.20 ± 0.11
	CG	26.3 ± 6.8	40.6 ± 5.7	33.4 ± 5.6	1.22 ± 0.13
EX	PG	21.6 ± 7.9	34.1 ± 11.4	35.3 ± 5.3	1.23 ± 0.12
	CG	28.4 ± 6.1	44.5 ± 6.6	39.4 ± 6.6	1.25 ± 0.14
PO	PG	24.7 ± 7.5	35.6 ± 7.1	31.7 ± 5.2	1.25 ± 0.11
	CG	28.3 ± 6.5	40.1 ± 6.8	34.2 ± 5.9	1.20 ± 0.14

The angular kinematics of the patients indicated that their range of motion was smaller than that of the healthy control subjects throughout the gait cycle. With respect to joint angles (Figures 1, 2 and 3), the patients showed changes as a consequence of the ACL reconstruction, mainly at the knee and ankle joints. During all phases of the gait cycle and under all conditions, both of these joints demonstrated reduced excursions with respect to the control group. However, the functional pattern of the flexion-extension angle was maintained. Ankle angular values (Figure 1) of the ACL reconstructed group were slightly different among the conditions, particularly from early to late swing.



(A)



(B)

Figure 1. Ankle angular displacement for patients (A) and control (B) subjects under the three conditions tested (Pre-exposure (PR), Exposure (EX) and post-exposure (PO).

Exposure caused the subjects to walk in a more flexed knee and ankle positions, particularly at early and mid-swing phases, as compared to the non-exposure conditions. The ACL-reconstructed and control groups' knee-position curves paralleled one another throughout stance and followed a flexion-extension-flexion pattern (Figure 2). After exposure, the kinematics for the patients' knee showed a partial return to pre-exposure values, however after about 60% of the gait cycle, the three curves presented different flexion values.

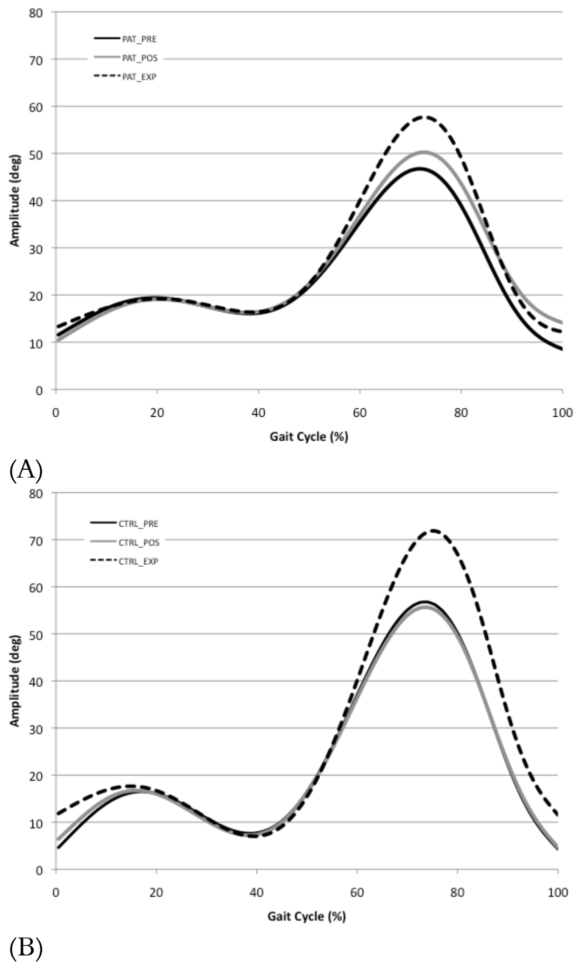
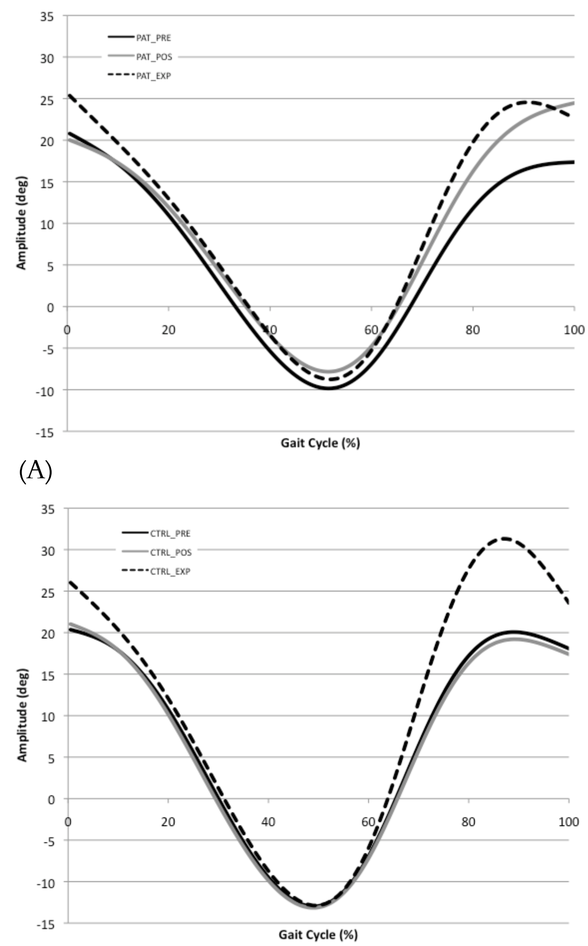


Figure 2. Knee angular displacement for patients (A) and control (B) subjects under the three conditions tested: Pre-exposure (PR), Exposure (EX) and post-exposure (PO).

Hip kinematics (Figure 3) was less affected by the exposure at the extension phase; essential changes were shown at late swing. Nevertheless, the patients group demonstrated an additional flexed pattern at the swing phase post-exposure as compared to pre-exposure.

Before the exposure, joint kinematics patterns in the ACL patients had similar features to the pattern in the control subjects, but with lower magnitude in flexion and extension. Exposure increased joint flexion responses for all subjects, whereas post-exposure control patterns approached pre-exposure patterns, for the patient group this was not always the case, except at the hip joint, where angular values of the ACL reconstructed group approached closer to the normal control subjects.

Studies on postural control adaptability to floor oscillations have suggested that postural responses are partially controlled by anticipatory mechanisms affecting the joint movement (BUCHANAN; HORAK, 2003, 2001), furthermore ACL patients may show adaptations to avoid knee instability (ZHANG et al., 2003). Other studies have shown lower extremity relative phase dynamics adjustments during walking and running, and altered gait pattern in ACL reconstructed patients evidencing a compensatory mechanism applied by this population (FERBER et al., 2002; KURZ et al., 2005; GAO et al., 2012). These deficits are identified as initial biomechanical gait responses to injury, surgery, and partial rehabilitation; also, suggesting learning periods for gait adaptations that might be related to learning process and the development of neuromuscular adaptations.



(B)

Figure 3. Hip angular displacement for patients (A) and control (B) subjects under the three conditions tested: Pre-exposure (PR), Exposure (EX) and post-exposure (PO).

Rehabilitation programs applying perturbation training showed satisfactory results, improving knee stability and strength, and restoring coordinated movement pattern (WILK et al., 2003; SHELBOURNE;

KLOTZ, 2006; MENDIGUCHIA et al., 2011). Lower extremity kinematics of ACL-reconstructed individuals, before and after exposure were fairly different from those of normal gait. The most notable difference was the tendency to improve knee flexion at early-mid swing phase compared with the flexion response in healthy individuals. Despite the reduced number of subjects participating in this study, our results suggested that repeated exposure to unstable surface allowed closing behavior to the normal gait patterns, indicating that this kind of exposure could result in relevant performance modifications. Also, therapy programs targeted towards a symmetrical pattern could lead to normal gait and functional activities. Generally, repeated exposure resulted in patterns closer to normal when comparing pre and post results, and these modifications could possibly be emphasized if exposure time and repetitions were prolonged. Surgical treatment cannot give satisfactory results without intensive and comprehensive rehabilitation, as well as a more individualized program.

Conclusion

Distinct adaptations to ACL injury and reconstruction have been observed in lower extremity kinematics, kinetics and EMG patterns (DEVITA et al., 1997; DELAHUNT et al., 2012; WEBSTER et al., 2012; HART et al., 2010; GAO et al., 2012) therefore an appropriate rehabilitation program can be a key factor to regain normal pattern. An ACL rehabilitation program often involves exercising on an unstable surface as the one presented here, thus biomechanical analyses of this type of testing can be used to improve rehabilitation protocols and promote a more individualized rehabilitation program (FELLER et al., 2004; SHELBOURNE; KLOTZ, 2006). Taking into account that the exposure introduced a challenge to subjects; postural compensatory mechanisms tend to be evidenced at the control subjects as compared to the patients. However, further controlled investigations of rehabilitation procedures are necessary to better understand how these techniques can best be applied and manipulated.

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