UNSTABLE 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. As ACL reconstruction becomes a more predictable and more frequently performed operation, there is an increasing desire on the patients for a rapid recovery of general gait function, which includes walking on unstable ground. Also, it is common for these patients to perform unstable surface training during clinical treatment. Therefore, 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 (double semitendinous tendon technique) and were at four weeks after the surgical intervention; and eight healthy subjects (control group) matched by age and gender. Participants walked at self-selected comfortable speed on an 8m-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 (5cm thick and 33kg/m² 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. Further investigation is necessary to expand our understanding and may improve the development of more effective rehabilitation treatments.

Key words: Anterior cruciate ligament, kinematics, gait, rehabilitation.

Palavras chaves: Anterior cruciate ligament, cinemática, marcha, reabilitação.

Estudos avaliando a marcha em pacientes com reconstrução do ligamento cruzado anterior (LCA) mostram diferenças em parâmetros cinemáticos, cinéticos e energéticos. A cirurgia de LCA tem-se tornado frequente e previsível, portanto existe um aumento no desejos dos pacientes em recuperar rapidamente a função da marcha incluindo o andar em superfícies instáveis. Sendo também comum para estes pacientes realizar treinamento neste tipo de superfície durante o tratamento clínico. Portanto, 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 (técnica utilizando o tendão duplo do semitendinoso) 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 8m enquanto os dados cinemáticos do plano sagital das articulações do membro inferior (quadril, joelho e tornozelo) eram obtidos com câmeras de 60Hz. Foram comparados os ângulos articulares em três diferentes condições: (A) caminhando na superfície estável, (B) caminhando num colchão (5cm de espessura e densidade de 33kg/m²), 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. Novos estudos são necessários para expandir nosso entendimento e talvez melhore o desenvolvimento de técnicas de reabilitação mais efetivas.

Key words: 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; Ciccotti et al. 1994; Andriacchi 1993; Timoney et al. 1993), 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 agreement 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 consensus of opinion is that the adaptations are caused by subconsciously learned, neuromuscular strategies owing to the injury. 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). 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). 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 ACL reconstruction (prolonged knee stiffness, limitation of complex extension, delay in strength recovery, anterior knee pain) (Shelbourne and Nitz 1992).

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 likelihood of returning patients to high-level physical activity. Therefore, the purpose of the study was to investigate the changes in select 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.

MATERIALS AND METHODS

The study was carried out with a group of 16 participants: eight subjects with ACL-reconstructed (double semitendinous tendon technique) (five males and three females) and eight normal subjects with no history of musculoskeletal pathology, matched by age and gender with the patients. 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 to full weight-bearing at the affected limb. 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, and all subjects provided written informed consent before testing.

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 (5cm thick and 33kg/m³ 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. 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 1992). The average trend for all variables was computed for each group. Groups and the three conditions (pre-exposure, exposure (foam mat), post-exposure) were compared using repeated measures analysis of variance (ANOVA) test. For the analysis we compared patients’ affected side, and matched with the respective control side.

RESULTS

Stride length was similar between the healthy and patient groups (Table 1); both groups walked approximately 1.23m 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 = 1.35m/s (patient group), mean = 1.53m/s (control group)). Our 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 = 34.9º) as compared to the control subjects (mean = 41.7º). Exposure conditions influenced the hip joint (P < 0.0001), as the range of motion for the non-exposure conditions (mean = 32.1º (patient group), mean = 33.8º (control group)) was smaller than those for the exposure condition (mean = 35.3º (patient group), mean = 39.4º (control group)).

Table 1. Joint range of motion and stride length for patients (P) and control (C) subjects under the three conditions tested (Pre-exposure (PRE), Exposure (EXP) and post-exposure (POS) (Mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Ankle (º)</th>
<th>Knee (º)</th>
<th>Hip (º)</th>
<th>Stride length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE P</td>
<td>23.7 ± 6.9</td>
<td>35.0 ± 4.6</td>
<td>32.5 ± 4.3</td>
<td>1.20 ± 0.11</td>
</tr>
<tr>
<td>PRE C</td>
<td>26.3 ± 6.8</td>
<td>40.6 ± 5.7</td>
<td>33.4 ± 5.6</td>
<td>1.22 ± 0.13</td>
</tr>
<tr>
<td>EXP P</td>
<td>21.6 ± 7.9</td>
<td>34.1 ± 11.4</td>
<td>35.3 ± 5.3</td>
<td>1.23 ± 0.12</td>
</tr>
<tr>
<td>EXP C</td>
<td>28.4 ± 6.1</td>
<td>44.5 ± 6.6</td>
<td>39.4 ± 6.6</td>
<td>1.25 ± 0.14</td>
</tr>
<tr>
<td>POS P</td>
<td>24.7 ± 7.5</td>
<td>35.6 ± 7.1</td>
<td>31.7 ± 5.2</td>
<td>1.25 ± 0.11</td>
</tr>
<tr>
<td>POS C</td>
<td>28.3 ± 6.5</td>
<td>40.1 ± 6.8</td>
<td>34.2 ± 5.9</td>
<td>1.20 ± 0.14</td>
</tr>
</tbody>
</table>

The angular kinematics of the patients indicated that their range of motion was smaller to 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 at 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 (Fig. 1) of the ACL reconstructed group were slightly different among the conditions, particularly in early to late swing.
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 (Fig. 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 showed different flexion values.

Hip kinematics (Fig. 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.

**DISCUSSION**

Distinct adaptations to ACL injury and reconstruction have been observed in lower extremity kinematics, kinetics and EMG patterns (Devita et al. 1997; Ciccotti et al. 1994; Timoney et al. 1993; Andriacchi and Birac 1993) 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). 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.

Studies on postural control adaptability to floor oscillations have suggested that postural responses are partially controlled by anticipatory mechanisms affecting the joint movement (Buchanan and 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 compensatory mechanism applied by this population (Ferber et al. 2002; Kurz et al. 2005). 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.

Rehabilitation programs applying perturbation training showed satisfactory results, improving knee stability and strength, and restoring coordinated movement pattern (Wilk et al. 2003). 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. Our results suggested that repeated exposure to unstable surface allowed closing behavior to the normal gait patterns, suggesting that this kind of exposure could result in relevant performance modifications. 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. Therefore, further controlled investigations of rehabilitation procedures are necessary to better understand how these techniques can best be applied and manipulated.

REFERENCES


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