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Research article

The role of anterior cruciate ligament in the control of posture; possible neural contribution

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ABSTRACT

The anterior cruciate ligament (ACL) is not only a mechanical structure for knee joint stability but is also a source of sensory information which could be used in the control of standing posture. It has been shown that the center of pressure (COP) time series during normal standing may be decomposed into two components which are hypothetically governed by different neural mechanisms, namely rambling and trembling. The aim of the present study was to investigate to what extent an injury to the ACL structure would affect these two control mechanisms. In this study the balance of a group of ACL deficient (ACLD) patients during double and single leg standing was examined and compared with that of a group of healthy individuals. We not only calculated the traditional measures of COP, but also decomposed this complex signal to investigate if ACL deficiency would affect the rambling and trembling components differently. The results showed that rambling was not significantly different between the two groups; however the trembling component was significantly greater for the ACLD group in both the single leg and the double leg condition. Further, there was also a component (rambling/trembling) by direction (anterior-posterior/mediolateral) interaction for both groups, indicating that the rambling component exhibited differences between directions of sway whereas the trembling component did not. This study provided evidence that the two components of postural control are differently affected by ACL deficiency, and that the rambling component is influenced by direction of sway.

1. Introduction

Anterior cruciate ligament (ACL) rupture is one the most prevalent injuries that could lead to knee joint deterioration and functional instability [1]. Ligaments are not simply a mechanical means by which the joint dampens excessive movements; rather, they are equipped with mechanoreceptors that transfer joint position information and movement sense to the spinal and supraspinal parts of the nervous system [2]. This information would in turn, affect both reflexive and voluntary movements [3]. For example Pitman et al., demonstrated that electrical stimulation of the ACL during arthroscopic surgery elicited somatosensory evoked potentials, suggesting that the ACL has cortical projections in man [4]. Similarly, Heroux et al., reported altered motor cortex excitability in the contralateral hemisphere in ACLD subjects when compared to healthy controls [5]. On the other hand, Solomonow et al. suggested the presence of a direct ACL reflex by showing that direct stress on the ACL inhibited the quadriceps and stimulated the hamstring muscles [6]. Therefore, with the existence of sensory receptors in the ACL it is highly plausible that the information originating from this structure can affect the control of upright posture. With the advances of analytical techniques for analyzing the COP during functional tasks, it is now possible to better examine the different contributing factors of postural control during quiet standing. Rambling-Trembling analysis is a technique which disassociates the compound signal of the COP into two hypothetical components. The first component serves to shift the COP from one equilibrium point to another and hence preserves the upright standing (the rambling component). This component is assumed to be centrally mediated. The second component is defined as the deviation of the first component from the compound COP (the trembling component). Since this second component generates a random signal, it is regarded as noise and therefore, assumed to be spared from central control but rather mediated by spinal pathways. By using the rambling-trembling technique, the two signals can be examined separately to reveal possible changes in the two components which could not be otherwise observed.

These two components are physiologically interpreted as a central and a peripheral controller of standing posture [7,8]. Since the introduction of this technique, many researchers have used it to provide

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new insight into the control of posture in various conditions [9] and possibly differentiate between the central and peripheral control of posture [10–12].

In this study, we have examined the control of posture in ACLD subjects during single leg and double leg standing with the rambling-trembling analysis. The significance of such a study is that it would provide evidence for the neural contribution of the ACL complex in controlling standing posture. The information obtained from the current study would potentially help in designing more accurate treatment plans for ACLD subjects. Current literature strongly suggests that postural control in ACLD individuals is impaired during single leg standing. This is the case while standing on the affected [12] and unaffected side either with closed or open eyes (reviewed in: Negahban et al., 2013) [13]. This led us to hypothesize that in these individuals postural control during double leg standing is most likely compromised but has been masked in the compound COP signal. Dissociation of the COP signal might be able to pinpoint any subtle changes in the components involved in the control of posture. Since both reflexive and voluntary modifications occur in ACLD individuals, and due to the fact that rambling and trembling are proposed to address central and peripheral postural control mechanisms, [11] the first hypothesis was that both rambling and/or trembling in either single or double limb support may be altered in ACLD subjects. We analyzed rambling-trembling in both the anterioposterior (AP) and the mediolateral (ML) directions. There is empirical evidence that COP characteristics may be affected differently in the ML and the AP directions [14–16]. The second hypothesis was that the rambling and trembling components may be differentially influenced by the direction of sway. Previous research has demonstrated significant deficits in postural control during single leg stance in ACLD subjects as compared to healthy subjects [17]. However, it is suggested that there is no significant alteration in postural control strategies during double limb support in these patients [12,18,19]. These studies have examined the changes in the COP as a postural control outcome measure. However, using traditional measures to study this complex signal might not be sensitive enough to show subtle neuromechanical alterations of postural control mechanisms.

2. Material and methods

Twenty healthy and twenty ACLD subjects participated in the study. ACLD subjects were recruited from the surgery waiting list of the patients whose injury occurred six to twelve months prior to the study (mean injury time = 8.37 ± 2.34 months). Their mean (± 1 SD) age, height and body mass were 27.45 (± 6.56) years, 174.65 (± 5.16) cm and 75.75 (± 7.65) kg, respectively. They were chronic (more than six months post-injury); right-sided, right leg dominant, complete ACL rupture with or without meniscal injury. Leg dominance was determined by asking the subjects to kick a ball and negotiate a flight of stairs. They were non-operated and non-coper. They were categorized as non-copers if they met one of the following criteria [20]:

1) Greater than two episodes of the knee giving way during normal daily activity since the injury;
2) Attained less than 60% of the pre-injury level in the global rating of function; and
3) Recorded less than 60% of the uninjured side value in the six meter timed hop test.

Patients did not report any accompanying ligament injury or neurologic disease. Their pain level was not more than three on the visual analogue scale (0–10).

Twenty healthy subjects participated as a control group in this study. Mean (± 1 SD) age, height and body mass were 26.45 (± 5.16) years, 176.05 (± 6.62) cm, and 74.37 (± 8.42) kg, respectively. They were right leg dominant as were the patients. In order to compare activity level of the two groups, the Tegner activity scale was recorded. This scale ranges between 0–10, with zero demonstrating complete bed rest and ten demonstrating most vigorous physical activities, such as rugby. This scale was 5.90 (± 1.55 SD) and 6.22 (± 1.43 SD) in healthy and ACLD subjects, respectively. The two groups were matched to age, height, body mass and activity level. All participants signed a consent form prior to participation in the study. This study was approved by the Ethics Committee of the Shiraz University of Medical Sciences.

3. Procedure

Force plate data were collected using a Kistler force plate (Portable Multi-component force plate type 9286B, Kistler, Winterthur Switzerland). In the first condition, participants stood quietly with both feet (double-leg) on the force plate with a comfortable foot position, approximately at hip width. In the second condition, subjects stood on their right leg (single-leg; all patients had right side injury). They were asked to put their arms beside their legs to avoid any upper extremity balance compensation. Subjects were barefoot in both conditions and gazed at a marker mounted on a target conventionally placed five meters in front of them to prevent them from looking down at their feet. Each balance recording lasted for 45 s with a one-minute rest interval. Sampling rate of the force plate was set to 120 Hz.

4. Analysis

All offline analysis was performed using custom written programs in Matlab (MathWorks Inc., Natick, MA). Raw data signals were filtered using a fourth-order Butterworth low-pass filter with a cutoff of 5 Hz. After filtering and detrending the COP data, the rambling and trembling components of the COP in the ML and AP directions were calculated based on the statistical method described by Zatsiorsky and Duarte [8,21]. Briefly, rambling represents displacement of the reference point around which the equilibrium is instantly maintained. At the discrete instances where horizontal ground reaction force equals zero (or very close to zero), these instant equilibrium points were estimated. The rambling trajectory was then reconstructed by interpolating these discrete points using cubic spline interpolation. The trembling component, which represents the oscillation of the COP around the rambling trajectory, was approximated by subtraction of the rambling component from the unitary COP. The root mean square of these signals was calculated to represent the characteristics of these signals. We also computed the traditional outcome measures: mean COP velocity in the AP and ML directions.

4.1. Statistical analysis

To examine the first hypothesis, a 2 × 2 (Group × Condition) analysis of variance was used to separately examine each component (rambling and trembling) of postural sway. Condition was a repeated measures factor. This was used to assess deficits observed in each component between the groups. To examine the second hypothesis, a separate 2 × 2 × 2 (Group × Component × Direction) was used to assess the influence of direction (AP vs ML) on each component (rambling vs trembling) of sway within each group. The component and direction factors were repeated measures. For all tests, the significance level was set to $p < 0.05$, and measures of the effect size (Cohen's d) were reported. Cohen's d was interpreted along traditional convention, with 0.2 indicating a small experimental effect, 0.5 a medium experimental effect and 0.8 a large experimental effect. All the statistical analyses were performed in SPSS 16.0 (SPSS Inc., Chicago, USA).

5. Results

The results of the two by two factorial analysis revealed no significant interaction between groups and conditions for either rambling