THREE DIMENSIONAL KINEMATICS AND LOWER LIMB EMG OF ACL DEFICIENT KNEE JOINT WEARING A FUNCTIONAL KNEE BRACE DURING RUNNING

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Knee braces have been found to provide limited stability to the ACL deficient (ACLD) knee in situations where the knee is loaded during sporting movements. Variability of the gait cycle of the injured knee during strenuous activity with and without a functional knee brace can be expected. Three dimensional (3D) kinematic and electromyography (EMG) data were collected for ten consecutive gait cycles from each participant after running 6 min on a treadmill under both braced and unbraced conditions. Bracing significantly reduced the abduction angle throughout the gait cycle however without reducing the total range of motion ($p < 0.05$). The functional knee brace showed a consistent trend of setting the ACLD knee in an external rotation position, thus avoiding internal rotation. Our findings supported the mechanical contributions of the brace in limiting abduction and suppressing internal rotation for ACLD knee during strenuous activities.

KEY WORDS: ACL, brace, electromyography, kinematics, running

INTRODUCTION: Functional knee braces are often used in rehabilitation treatment to compensate for deficiencies or to return to sport competition faster. One may find it to be helpful although their efficiency has been questioned. In 2004, Genty and Jardin reviewed over 90 papers on the efficiency of knee braces and reported that most of studies confirmed the stabilizing effect of the brace of the injured knee in lab settings, but nothing can be concluded for activities performed in real life conditions. It was also put forward, by other studies, that proprioception could be the main influencing factor induced by the brace (Ramsey, Wretenberg et al. 2003).

Wearing knee brace for a long period of time while performing sport activity could induce muscle fatigue. Verkerke et al. (1998) were able to establish a relationship between muscle fatigue and step parameters during running. It has been shown that step variability was initially high and then progressively decreasing as a function of time, the steps parameters remained stable until muscle fatigue appeared, after few minutes of running. The purpose of this study is to verify the effects of the functional knee brace on kinematics and muscle activity of the lower limb during running for six minutes on treadmill.

METHOD: A group of 11 ACLD male participants were recruited among patients who were diagnosed as having an ACL tear by an experienced orthopaedic surgeon at the Carleton University Sports Medicine Clinic in Ottawa. All the ACLD participants were clinically assessed with the KT 1000 arthrometer (MEDmetric Corporation, San Diego, USA) and compared with the contralateral leg. All participants obtained a minimum laxity score of +3. At the time of the testing session, all participants exhibited full knee range of motion and no pain during walking or running. Participants were excluded if they had used a functional knee brace on the injured knee prior to the experimentation. Only male participants were included in this study because of both anatomical and biomechanical differences between genders.

Prior to the running trials, the DonJoy 4titude knee brace (dj Orthopedics, Inc., California, USA) was fitted to each participant according to the manufacturer's guidelines and specifications prior to the testing session. Participants were then allowed a warm-up period of five minutes on the treadmill in the braced condition to determine a comfortable running speed. The participants were then required to perform a six minute running period on the treadmill under both conditions (braced and unbraced). Data were collected for a period of ten seconds during the last minute of the six minute running period. A total of ten running cycles were used for data analysis.

Four high-speed digital video cameras (JVC GR-DVL9800), connected to a PC computer equipped with the SIMI* Motion system (SIMI* Reality Motion Systems GmbH), were positioned in a semi circle along the side of the participants' injured leg to record all trials. The cameras recorded at a speed of 60 Hz and were zoomed to include only the ACL deficient limb in the field of view. The calibrated volume was approximately 1.5 m x 1.0 m x 0.75 m. Prior to the experimental trials, a standing joint coordinate system (JCS) trial (Grood and Suntay, 1983) was also taken to allow for knee joint 3D kinematics. The JCS is defined as a series of eight markers placed on anatomical landmarks on the participant's injured leg to define the anatomical axes of the knee joint. During all trials, nine reflective markers (three markers per segment) remained on the participant's injured limb, which were visible at all times in at least two camera views. A sound signal generated by the footswitch of the EMG system and transmitted directly into the video cameras was used at the beginning of all trials to synchronize all instruments and to provide an accurate indication of heel-strike. In addition to 3D kinematic data, EMG signal (Bortec Biomedical Ltd., Calgary, Canada) was used to record muscle activity on both lower limbs of the participants during all trials. The surface EMG electrodes (Blue Sensor Ag/AgCl) were positioned on the Vastus Lateralis (VL) and Medialis (VM), Biceps Femoris (BF), Semitendinosis (ST), the Gastrocnemius Lateralis (GL) and Medialis (GM) muscles.

Three-dimensional kinematics and EMG data were processed and analyzed for ten consecutive running cycles (heel-strike to heel-strike) using the SIMI* Motion system (SIMI* Reality Motion Systems GmbH). All ten consecutive cycles were averaged for every participant in both conditions. EMG signals were baseline corrected and low pass filtered (2^{nd} order Butterworth) at 6 Hz to produce a linear envelope. From the linear envelope EMG (LE EMG), the amplitudes at heel-strike, and the area under the curves (ILE EMG) were obtained for each muscle and compared across conditions. The 3D coordinates of individual segment and JCS markers were then converted into segmental data using custom-made software in MatLab (The Mathworks, Inc. USA) to obtain the 3D joint kinematics of the injured knee. Peak angular values (flexion/extension, abduction/adduction, internal and external rotations), time to peak angles, and total ranges of motion were compared between conditions.

Statistical analysis of both the EMG and 3D kinematic data focused on comparisons between the braced and unbraced conditions. The Student's t-test with a p value of 0.05 was used to compare between conditions for both the EMG and 3D kinematic data. Variables compared for the kinematic data were taken from the sagittal (flexion/extension), frontal (abduction/adduction) and transverse planes (internal/external rotation). Variables compared for the EMG data included both amplitude and timing characteristics of the signal. Amplitude parameters were characterized by peak amplitude at heel-strike and LE EMG area (ILE EMG) for both experimental conditions. In the case of the EMG, data from each muscle was compared separately for the dependant variables across both conditions.

RESULTS: Bracing the ACLD knee resulted in a decreased peak abduction angle compared to the unbraced condition ($p < 0.05$). The brace showed a tendency to amplify the peak flexion and extension angles at the end of the six minutes period. It can also be observed that our data showed no internal rotation while braced, in contrary with the unbraced condition (Figure 1). In addition, only the GM was modified by the brace, significantly lowering the LE EMG magnitude at heel strike ($p < 0.05$) (Figure 2).

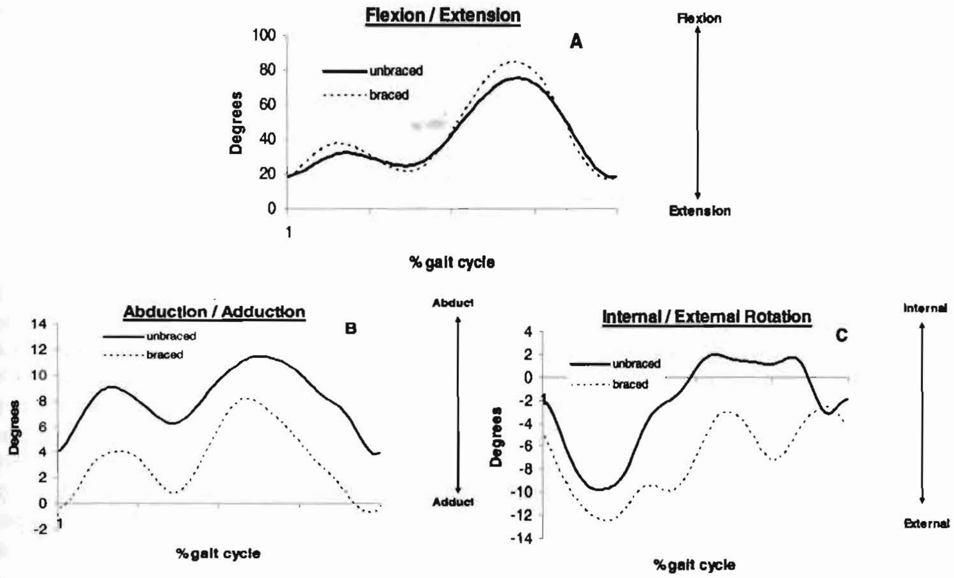

Figure 1 Sagittal plane (A), frontal plane (B) and transverse plane (C) knee joint angle in the braced and unbraced conditions.

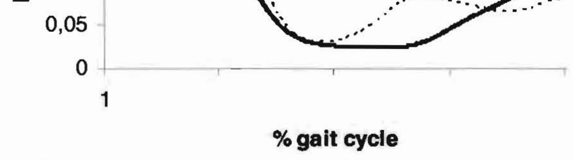

Figure 2 LE EMG profile of the Gartocnemieus Medialis muscle during running for the aced and unbraced conditions showing the differences in amplitude at heel-strike.

DISCUSSION: The data, collected after six minutes of running, were compared between the braced and unbraced condition. The functional knee brace also showed a tendency to modify the kinematics at the end of the six minutes period. The internal rotation found in the unbraced condition seemed to be avoided in the braced condition, leaving the knee in an external rotation throughout the gait cycle. This implies that the brace could positively place the knee during exhausting activities in an external rotation which can significantly reduce the stress imposed on the ACL as reported by other studies (Ramsey, D. K., P. Wretenberg, et al. 2003). Furthermore, the abduction/adduction movement of the knee has also been modified by the brace. As Figure 1 shows, bracing resulted in a reduction of knee joint abduction

angle. While these angles were reduced, it can be observed that the general appearance of the abduction adduction curve has not been modified. This suggests that the functional knee brace could be able to reduce the peak angle of abduction while running, therefore placing the joint in a more neutral position. In addition, while it was reported by Verkerke et al. in 1998 that the variance in step parameters increases in relation to muscle fatigue, our findings suggested that wearing a functional knee brace could reduce theses variances. All subjects, after the six minutes of running on the treadmill, appeared to maintain a certain consistency in their kinematics over the gait cycle. This indicates that the brace could act as a guide for movement, accordingly reducing the variability of step parameters even as fatigue sets in. Bracing the injured knee, even after undergoing ligament reconstruction, could then be a complimentary treatment for patients with desire to maintain an active lifestyle.
Furthermore, the brace showed a tendency to decrease EMG parameters at heel strike for all muscles, except the ST. Although this tendency could be easily observed, no significant differences could be found using the t-test between the brace and unbraced condition. However, the GM muscle is the only muscle that did show a significant difference at heel strike ($p < 0.05$). Bracing the injured knee resulted in a decrease of almost half the original EMG. It is our judgment that the lack of significant differences between conditions for the other muscles could be attributed to the high variance among subjects. In accordance with current literature, it is most difficult to clearly establish a modification pattern in muscle activity associated with the braced condition amongst subjects (Smith, Malanga et al. 2003). One explanation could be the coping mechanism being different for each subject, dominating over the possible modification induced by wearing the brace. These mechanisms would then be specific to each subject, not to the brace itself.

CONCLUSION: This research has shown that the functional knee brace could have a positive influence on the injured knee. Due to the small number of subjects, only a few significant differences between the conditions were observed. Although, the results clearly demonstrated that the kinematics of running is modified by the brace. Suggestions for future studies would include the use of a larger number of subjects, a longer running period to ensure considerable muscle fatigue and a faster running speed. These changes would possibly reveal significant findings, consequently helping to understand the influence of the functional knee brace on anterior cruciate ligament deficient knee in real sport setting.

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