BIOMECHANICS OF NORMAL AND ANTERIOR CRUCIATE LIGAMENT DEFICIENT GAIT UNDER BRACED AND UNBRACED CONDITIONS

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INTRODUCTION

The anterior cruciate ligament (ACL) plays an important role in maintaining the integrity of the knee joint during the support period of gait. Unfortunately, rupture of the ACL is a common injury to the soft tissue of the knee. If the ACL is ruptured, the individual may compensate by altering their gait mechanics to reduce the accompanying knee instability. Several studies have investigated the affects of ACL-deficiency. However, the examination of ACL-deficiency has focused on only the knee joint. This approach does not provide a complete understanding of how the lower limb responds as a unit (including the hip, knee, and ankle) to compensate for ACL-deficiency. To date, few studies have considered the possible compensatory mechanisms acting in the lower limb during running. Quite often a knee brace is used to help stabilize the ACL-deficient knee. Several de-rotation knee braces have been developed to perform this task. Examination of brace function has focused on the ability of the brace to limit transverse tibial rotation, prevent anterior displacement of the tibia; and affect performance time, energy consumption and muscle force output at the knee. However, the primary objective of the brace is to counteract knee instability. The mechanics adopted by the braced ACL-deficient limb during gait have been a secondary concern and are therefore not well understood (Corcoran, Jebsen, Brengelman, and Simons, 1970; Houston and Goemans, 1982; Jonsson and Karrholm, 1990).

The purpose of the present study was to complete a biomechanical comparison of selected running gait mechanics of normal and ACL-deficient individuals in order to look for strategies common to ACL-deficient individuals used to compensate for ACL-deficiency. The examination of the effects of de-rotation knee braces on running mechanics was to provide insight into the advantages and disadvantages and wearing a brace. Specifically, the purposes of this study were to: 1) Determine if ACL-deficient gait is different from normal gait. 2) Determine if knee bracing affects gait. 3) Determine if braced ACL-deficient gait is different from normal unbraced gait.

METHODS

Seven male ACL-deficient subjects (X age = 25 ± 5 years, X height = 1.80 ± .07 metres; X mass = 85.0 ± 16 kg) were recruited through the University of Windsor Therapy Clinic. Medical histories verified ACL-deficiency in each of the subjects and all subjects reported an initial injury occurrence during athletic activity. Seven normal male volunteers (X age = 24 ± 2 years, X height = 1.80 ± .05 metres, X mass = 86.0 ± 5 kg) were recruited to serve as a control group. There were no statistically significant between group differences for age, height or body mass. Prior to testing, members of the normal group were given de-rotation braces to wear during practice. They were instructed to run at a medium jogging pace a significant number of times to ensure a satisfactory comfort level during the wearing of a brace.

All subjects were tested under both braced and unbraced conditions while running at a cadence of 77 cycles-per-minute. Therefore, the running velocity was approximately 3.5 metres per second. During each trial one support period was monitored through use of an AMTI force platform operating at a sampling rate of 100 Hz. Also, each trial was filmed using a LOCAM 16mm high speed camera operating at a film rate of 50 Hz.

Segmental end point data for the lower limb were measured using an Altek AC 30 digitizer connected on line to a microcomputer. The film data were filtered at a cut off frequency of 5 Hz. using a fourth order low pass digital filter. Running velocity, cycle length, and vertical displacement of the centre of gravity were calculated from filmed data.

The net muscle moments of force at the ankle, knee, and hip were calculated using an inverse dynamics procedure which combined GRF data, kinematic data, and subject anthropometric data in standard NEWTONIAN equations of motion. Ankle, knee, and hip muscle moment curves were summed on a point-by-point basis to calculate the support moment for each trial. The muscle moment curves were normalized to 100-point data sets using an interpolating software routine. Average muscle moment curves were then calculated for both normal and ACL-deficient subjects under braced and unbraced conditions. From the muscle moment curves, average and peak extensor moments of force were determined. All kinetic data were normalized to body mass before averaging to allow meaningful between group comparisons.

Values for each dependent variable were calculated for each subject under braced and unbraced conditions. A separate 2 x 2 (level of deficiency X bracing) repeated measures analysis of variance was performed on each dependent variable to test for statistically significant differences between variables. Statistically significant differences were accepted at alpha $< .05$.

RESULTS

Basic kinematic data for normal and ACL-deficient subjects under both braced and unbraced conditions are listed in Table 1. The mean cycle lengths as recorded from film for the ACL-deficient subjects was 1.66 and 1.68 times height for the braced and unbraced conditions respectively. For the normal subjects under braced and unbraced conditions the cycle lengths were 1.59 and 1.58 times height respectively. These values reflect no statistically significant differences between ACL-deficient and normal subjects or between braced and unbraced conditions. The mean position of the centre of gravity with respect to the knee joint during support was negative for both braced and unbraced conditions in each of the ACL-deficient and normal groups. However, again there were no statistically significant between group or between condition differences. Finally. the mean vertical displacements of the centre of mass during the running cycle expressed as a percentage of standing height were slightly higher for the ACL-deficient group than for the normal group under both of the braced and unbraced conditions. However, the values of 6.07 and 6.68 were not statistically significantly different from the values of 5.79 and 5.46 percent for the normal subjects. In summary, it appears that rehabilitated ACL-deficient subjects run with similar running kinematics to normal subjects and that the wearing of a de-rotation brace has no significant effect on running kinematics.

All values were normalized to body weight to provide a basis for between group comparisons. The mean total peak support moment for the leg was 6.72 N.m/kg and 7.38 N.m/kg for the braced and unbraced conditions in the ACL-deficient group. These values were comparable but slightly higher than those found for the normal group in which the braced condition resulted in a mean value of 6.60 N.m/kg and the unbraced condition a mean value of 6.62 N.m/kg. Analysis of variants revealed no statistically significant between group or between condition differences. The values calculated in this study for peak support moments were similar to those reported by Blankenship-Hunter in a 1990 study. Further analysis was carried out to look at individual joint moments during the running cycle. The peak hip moments for the

ACL-deficient and normal subjects under braced and unbraced conditions were 3.21, 4.28, 3.60, and 3.28 **N.m/kg** respectively. These results confirm no statistically significant between group or between condition differences. Peak moments at the **knee** of 1.32, 1.40, 1.72, and 1.82 **N.m/kg** were found for the braced and unbraced conditions of ACL-deficient and normal subjects respectively. Once again although slight differences were found between the ACL-deficient and normal groups these differences were **not** statistically significant. Finally. the peak ankle moments calculated for ACL-deficient and normal groups respectively were 3.47, and 3.72 **N.m/kg** and 3.83 and 3.70 **N.m/kg** in the braced and unbraced conditions. Again, no statistically significant differences were found between groups or between conditions.

Table 1: Kinematic Variables for Normal and ACL-Deficient Subjects under Braced and Unbraced Conditions

Variable	ACL-Deficient * (N=7)		Normal (N=7)	
	Braced**	Unbraced	Braced	Unbraced
Cycle Length **M/ht**	1.66 **(.29)**	1.68 **(.34)**	1.59 **(.15)**	1.58 **(.19)**
C.ofGrav.Pos. (M/ht) x 100	-4.50 (2.73)	-4.90 (2.34)	-3.19 (1.56)	-4.08 (1.39)
Vertica Disp. (M/ht) x 100	6.07 (1.38)	6.68 (.92)	5.79 (2.42)	5.46 (1.86)

* P > .05

** P > .05

The mean total peak support moments as well as individual peak moments for the hip, knee and ankle joints are listed in Table 2.

Table 2: Peak Support Moments for Normal and ACL-Deficient Subjects Under Braced and Unbraced Conditions

Variable	ACL-Deficient * (N=7)		Normal (N=7)	
	Braced**	Unbraced	Braced	Unbraced
Peak Supp. Moment (N.m/kg)	6.72 (1.15)	7.38 (1.55)	6.60 (1.34)	6.62 (1.72)
Peak Hip Moment (N.m/kg)	3.21 (1.05)	4.28 (2.32)	3.60 (1.35)	3.28 (1.03)
Peak Knee Moment (N.m/kg)	1.32 (.38)	1.40 (.83)	1.72 (.65)	1.82 (.96)
Peak AnkleMoment (N.m/kg)	3.47 (.53)	3.72 (.96)	3.83 (.80)	3.70 (.79)

* P > .05 ** P > .05

DISCUSSION AND CONCLUSIONS

The results of the present study indicate that for the recruited population, ACL-deficiency may not alter running mechanics during the performance of a non-fatigued moderate velocity straight-line **running** task. Furthermore, bracing the ACL-deficient limb appeared to have no affect on gait mechanics during this type of activity. No statistically significant interactions were found between normal and ACL-deficient subjects and bracing. This suggested that the running mechanics of unbraced normal subjects were similar to the mechanics of braced ACL-deficient subjects. The results of this study support Blankenship-Hunter (1990) who found that bracing the ACL-deficient limb did not alter lower limb muscle moments.

The ACL-deficient subjects tested in this study were well rehabilitated, active individuals. No consistent differences were noted between the thigh girths of the sound and the deficient limbs, suggesting that muscle strength was similar between limbs. The study of ACL-deficiency may therefore require less rehabilitated or newly injured subjects. A larger subject pool may have produced statistically significant differences. Typically, studies of ACL-deficiency have reported using less than ten subjects. Seven ACL-deficient subjects were recruited for this study. Although the running mechanics of the normal and ACL-deficient subjects in the present study were not statistically different, the data appeared different and suggested that a more severe running task accompanied by more subjects or trials may have produced significant differences. In future investigations, an examination of the muscle forces produced in specific events during the support period (particularly during loading) may provide important information about ACL-deficient running mechanics. The results of this study also show how the lower limb functions as a unit during the support period and reveals the limitations involved in focusing on the knee joint alone when describing ACL-deficient gait. Comparing ACL-deficient subjects to normal individuals provided reference data which enhanced the evaluation of the effects of ACL-deficiency.

Blankenship-Hunter (1990) concluded that bracing effects were secondary to internal compensation and habituation to the original injury. In the present study, any internal compensation by ACL-deficient subjects to the injury that may have been present seem to have disappeared. For these subjects. the use of a knee brace for moderate, low risk activities may provide only a psychological feeling of stability while wearing the brace. The results of this study may also suggest that knee braces are beneficial since they did not appear to alter running mechanics during a moderate running task. Perhaps a more revealing assessment of wearing a knee brace on running mechanics requires using a more stringent experimental protocol which may include using a greater running velocity, gait perturbations. or increasing the duration of the run to introduce an element of fatigue.

In summary, based on the results of this study and within the limitations of the study the following observations warrant consideration: 1) The gait mechanics of well rehabilitated, ACL-deficient subjects may not be different than the running mechanics of normal individuals during a non-fatigued, moderate intensity, straight-line running task. 2) Bracing the knee may have no impact on running mechanics during moderate, low risk activity. 3) The gait mechanics of braced ACL-deficient runners may not be different from the mechanics of unbraced normal runners.

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