THE EFFECT OF ACL RECONSTRUCTION ON LOCOMOTOR VARIABILITY

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INTRODUCTION

Anterior cruciate ligament (ACL) ruptures are among the most common and debilitating injuries in sports and usually require surgical intervention (Timoney et al, 1993). There is much debate concerning biomechanical changes associated with ACL reconstruction. Due to the uncertainty present when traditional biomechanical parameters are evaluated, it may be necessary to seek alternate approaches to identify the effects of ACL reconstruction on gait. ACL rupture and reconstruction may cause changes in neuromuscular variability. This variability has been described as a “healthy” flexibility within the neuromuscular system (Pool, 1989). Severe injury can possibly result in a loss of this flexibility that may not be regained despite surgical treatment. The purpose of this study was to examine differences in variability during locomotion following ACL reconstruction. We used tools of mathematical chaos to examine variability.

PROCEDURES

Ten subjects who had undergone ACL reconstruction using an autogenous patellar tendon graft and who were fully rehabilitated (months post-surgery = 40.55$\pm$ 49.56), and ten healthy controls participated in the study. Kinematic data from 30 continuous footfalls were collected at 60 Hz from both legs of the experimental group and the left leg of the control group, while the subjects walked and ran on a treadmill at their self-selected pace. The time series from the unfiltered relative angles of the knee and ankle joints were analyzed using the Chaos Data Analyzer software (Sprott, 1992).

Lyapunov Exponents (LyE) and Correlation Dimensions (COD) were calculated for both legs-groups. LyE is a measure of the stability of an attractor and its dependence on initial conditions. COD describes the geometric dimension of an attractor in the state space. All calculations were performed using 5 embedded dimensions. The embedded dimension, a description of the number of dimensions needed to unfold a given attractor, was calculated from a Global False Nearest Neighbor (GFNN) analysis (Abarbanel, 1996).

The angular data was also surrogated using a phase randomization technique (Dingwell et al., 2000). Surrogation removes the deterministic structure from the original data set, generating a random equivalent with the same mean, variance, and power spectra as the original. The surrogate data set is then analyzed in a similar manner to the original. If significant differences are found between the two data sets, then the original is not a randomly derived data set. Mean group values were calculated for LyE and COD for both legs-groups of the original and surrogate data sets for running and walking and were analyzed statistically using independent and correlated t-tests ($p < 0.05$).

RESULTS AND DISCUSSION

No significant differences were found for either LyE or COD for running. In walking, the results identified significant differences in the ankle LyE and the knee COD between the ACL reconstructed leg and the control. Knee and ankle LyE of the non-injured leg were found to be significantly smaller than the control. Furthermore, the control LyE for both joints were larger than the experimental group for both legs. This may indicate that variability differences exist between the two groups during walking. These differences may be the result of the rupture and the subsequent reconstruction. The knee COD for the ACL reconstructed leg was also found to be greater than the non-injured leg during walking. All LyE were found to be positive, suggesting the existence of chaotic dynamics within the data. Significant differences in LyE between the original and surrogate data sets for all variables analyzed confirmed that the original data sets were not randomly derived and had deterministic origin. This result indicates that the neuromuscular variability may be chaotic in nature. As it has been indicated (Pool, 1989), such chaotic behavior may allow the nervous system to adapt to changing conditions, while generating effective movement patterns.

SUMMARY

Variability in locomotion of surgically treated and control subjects was found to be clearly distinguishable from random noise. This may indicate that the lower extremity exhibits chaotic behavior during both walking and running. ACL reconstruction seems to preserve control strategies employed by the nervous system to generate effective locomotor movement patterns. However, variability differences do exist during walking between healthy controls and individuals with surgically reconstructed knees.

REFERENCES

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Table 1: Group means of Original and Surrogate data during walking and running.

	WALK			**RUN**		
	LyE	**S-LyE**	**COD**	**LyE**	**S-LyE**	**COD**
ACL Leg-Knee	0.086	0.260♣	2.731*†	0.093	0.268♣	2.079
Healthy Leg-Knee	0.084*	0.266♣	2.425	0.097	0.267♣	2.046
Control Knee	0.107	0.260♣	2.360	0.108	0.256♣	2.076
ACL Leg- Ankle	0.140*	0.313♣	3.343	0.151	0.285♣	2.863
Healthy Leg-Ankle	0.140*	0.324♣	3.254	0.148	0.285♣	2.974
Control Ankle	0.173	0.325♣	3.496	0.147	0.279♣	3.090

*Sig. different to the control; †Sig. different to the healthy leg; ♣Sig. different to original data set