

DECREASED COMPLEXITY IN LEG MOTION PATTERNS DURING WALKING IN KNEE OSTEOARTHRITIS

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INTRODUCTION

The theory of chaos considers homeostasis to be characterized by "chaotic" properties or complexity in a biologic system that provides the necessary flexibility to adapt to external stresses, as well as to physiological "noises" in biological systems [1]. This concept has led to the "loss of complexity hypothesis", in which high system complexity is described as healthy, while decrease of system complexity is associated with pathology.

In the case of walking, flexibility in leg motion control presumably plays a crucial role in stable locomotion. Measurement of such motion control flexibility is anticipated to help understand the mechanisms of functional impairment associated with lower-extremity pathologies. In this study, we explored the chaotic property of leg motion patterns during walking by means of accelerometry, in older adults with symptomatic knee OA and in control subjects. It was hypothesized that those with symptomatic OA would exhibit less complexity in leg motion patterns than control subjects.

METHODS

A total of one-hundred and two volunteers (Table 1), including subjects with symptomatic knee OA ($n = 55$) and control subjects ($n = 57$), were recruited with IRB approval (#200907764). These subjects underwent a long distance corridor walking test. The OA subjects were asked to walk 400 meters (20 laps in a 20 meter walkway) at the quickest pace that he/she could maintain for that distance (or if he/she felt unable to walk 400 meters, then to walk for 2 minutes at his/her quickest pace). Control subjects completed two sessions of 200-meter walking test, one at a self-selected pace and the other at his/her quickest pace. Each walking test was timed, and the average speed was computed.

Leg motions during the walking test were measured using a light-weight wireless activity monitoring system (DigiTrac[®], IM Systems Inc., Baltimore,

MD), attached bilaterally just above each ankle using Velcro. This device measured/recorded tri-axial accelerations of the lower leg segment, at a sampling rate of 40 Hz. The data recorded were analyzed using a custom Matlab program, to compute a chaotic non-linear measure "sample entropy (SampEn)" [2]. SampEn (m, r, N) quantified the complexity of a time-series dataset consisting of N data points, by assessing the probability that equal sequences of length m , would remain similar after a time increment. The degree of similarity was determined by the tolerance r . The output was a unitless, non-negative number where lower values indicate more regular signal and higher values more complex signal. This measure of chaos was calculated for acceleration data in each axis (anterior-posterior, proximal-distal, or medial-lateral), as well as for the sagittal-plane 2D-acceleration data (combination of the anterior-posterior and proximal-distal data) and for the 3D acceleration data, at 10 second intervals ($N = 400$), with the other parameters set at typical values, " $m = 2$ " and " $r = 0.2$ ".

RESULTS AND DISCUSSION

In the control subject data (Figure 1), there was a trend that the SampEn measures became higher when a subject walked at a faster pace (1.3 ± 0.1 fold faster than the self-selected pace). Of the SampEn measures studied, the medial-lateral axis data (SampEn-ML) were least affected by walking speed (difference between sessions was 1.1 ± 0.1 fold), and data for each individual subject were well correlated between walking sessions ($r = 0.86$). In addition, SampEn-ML did not significantly differ by sex ($p = 0.31$).

Figure 2 is a scatter plot of SampEn-ML vs. age, in the control (at the self-selected pace) and OA subjects. In the control group, there was a weak (but significant) trend that SampEn-ML decreased with age ($r = -0.218$, $p < 0.001$). OA subject data appear to deviate from control data. Figure 3 shows a

statistical comparison between the control and OA groups in the subjects matched by age (53 – 79 years) and walking speed (1.2 – 1.6 m/sec). There was evidence that SampEn-ML in these selected OA subjects was significantly lower ($p < 0.001$) than in the matched controls, suggesting reduced complexity in medial-lateral leg motion patterns in OA subjects.

CONCLUSIONS

Leg motion patterns during walking in symptomatic OA subjects were characterized by decreased complexity (stride-to-stride variability) in the medial-lateral acceleration time sequence. Reduced motion pattern complexity associated with knee pathology is consistent with previous observations in patello-femoral pain syndrome [3] and ACL deficiency [4]. Given that OA knees often have coronal-plane malalignment, the reported abnormality may be associated with reduced ability to accommodate load re-distribution between medial/lateral compartments. The present leg motion complexity measurement technique does not require elaborate gait analysis equipment, and therefore lends itself to multi-institutional studies. As SampEn-ML provides a gait velocity-independent measurement of motion pattern complexity, this may be a valid and convenient clinical tool for intra-patient (before vs. after therapy) as well as inter-patient (screening for gait impairments) assessments.

REFERENCES

1. Lipsitz LA and Goldberger AL. *Jama* 267, 1806-09, 1992.
2. Richman JS and Mooran JL. *Am J Physiol Heart Circ Physiol* 278, H2039-49, 2000.
3. Hamill J et al. *Clin Biomech* 14, 297-308, 1999.
4. Moraiti CO et al. *Knee Surg Sports Traumatol Arthrosc* 15, 1406-13, 2007

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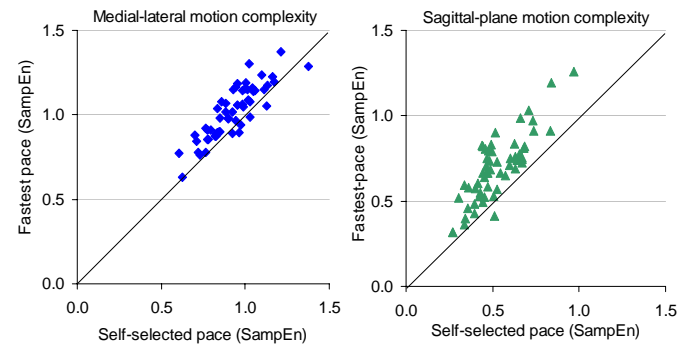


Figure 1. Correlation of SampEn values between walking sessions. Central lines indicate the “1 : 1” relationship.

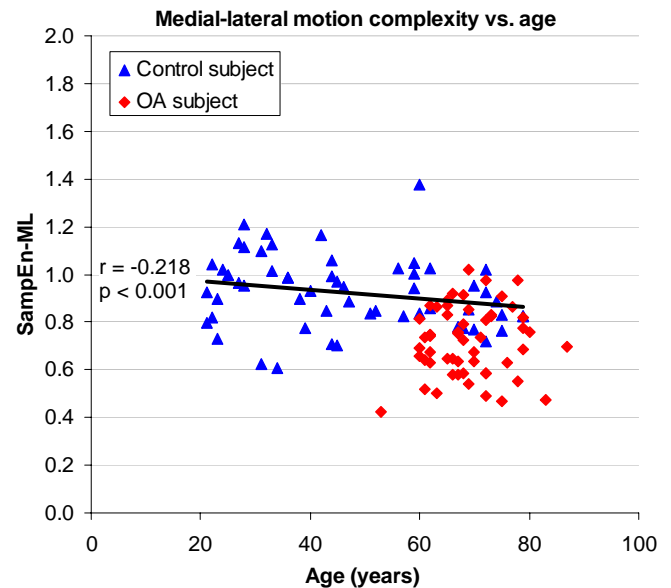
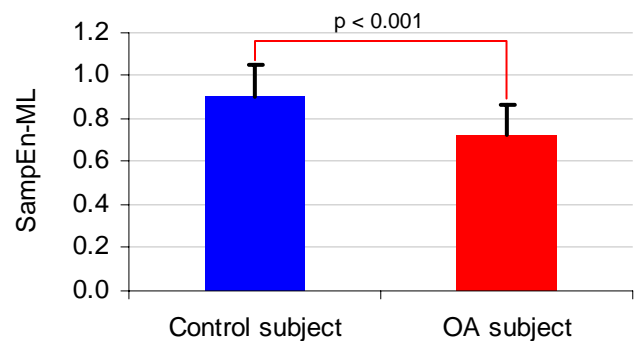


Figure 2. Relationship of SampEn-ML data with age.



Number (F : M):	22 (12 : 10)	27 (18 : 9)
Age (year):	67.1 ± 7.3	66.0 ± 6.0
Speed (m/sec):	1.4 ± 0.1	1.3 ± 0.1

Figure 3. Comparison of SampEn-ML between groups in matched subjects. Values are mean ± SD.

Table 1: Demographic of study participants and the walking speed data

Group	Number (female : male)	Age range (mean)	Walking speed (m/sec): range (mean ± SD)	
			Self-selected pace	Fastest pace
OA subject	55 (37 : 18)	53 – 87 (68.8)	Not tested	0.4 – 1.6 (1.2 ± 0.2)
Control subject	57 (29 : 28)	21 – 79 (47.0)	1.0 – 1.7 (1.4 ± 0.1)	1.5 – 2.3 (1.9 ± 0.2)