THE EFFECT OF SURGICAL ALIGNMENT ON STANDING BALANCE IN ADULT DEFORMITY PATIENTS – INVARIANT DENSITY APPROACH

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INTRODUCTION

Adult degenerative scoliosis (ADS) patients comprise a variety of conditions that affect the normal spinopelvic alignment in the coronal and or sagittal planes. In spinal deformity patients a variety of postural changes in the spine, pelvis and lower extremities are observed in their effort to compensate for the anterior shift in the gravity line. Spinal alignment surgery was found to improve balance and overall function. Balance is defined as the ability of the human body to maintain its center of mass within the base of support with minimal postural sway. Sway can be measured as the center of pressure (COP) movement when a person is standing in a static position.

Objective of this study is to investigate the effect of surgical alignment on postural sway in ADS patients both before and 3-months-after-surgery.

METHODS

Clinical gait analysis was performed on eighteen ADS patients. Each patient performed a series of functional balance tests one week prior (Pre) and 3 months post-surgery (Post) one week prior and 3 months post-surgery. The functional balance test was similar to a Romberg's test in which the patients were asked to stand quietly with each foot on a force platform (i.e., total two force platforms) in a self-selected posture with eyes open for a full minute. Force platform data were used to compute COP measures in both anterior-posterior (AP) and medial-lateral (ML) directions. Two postural sway assessment techniques were used for analysis: 1. traditional summary COP descriptive measures [1]; and 2. invariant density analysis [2] which describes the dynamic COP distribution over time.

Traditional COP measures, *Range* and *Mean Velocity* of COP were also examined to provide statistical description. The stochastic structure of postural sway was analyzed using a reduced-order finite Markov-chain model [2]. The location of the COP can be categorized as different states emanating from the centroid. It has been shown that the distribution of COP over the state space converges to a unique steady state distribution π, known as invariant density [2]. Therefore, by understanding the invariant density, we can observe the long-term postural sway behavior. Five parameters were used to characterize the invariant density to better understand the system dynamics. This technique is called Invariant Density Analysis (IDA) [2]. In this study, we examined five IDA parameters: *Ppeak*, *MeanDist*, *D95*, *EV2*, and *Entropy*. *Ppeak* is the largest probability of π. *MeanDist* is the average location of the COP. *D95* is the largest state at which there is a 95% probability of containing the COP. *EV2* is the 2nd largest eigenvalue of the transition matrix and describes the convergence rate of the system to the invariant density. *Entropy* is the measure of randomness.

In addition to the existing IDA parameters, we introduced one more new metric that provides insight into the control mechanisms of the postural control system. As suggested in [3], the eigenvector corresponding to the second largest eigenvalue is of our interests. Hur [3] noted that investigation of the second eigenvector has the potential to provide a complete understanding of the embedded dynamics in the reduced order model. Recently, [48] reported that the state space could be subdivided into two subsets depending on the sign of the corresponding second eigenvector (i.e., positive vs. negative). Each subset shows different dynamic behavior. Using this idea, we will investigate the zero crossing point of the second eigenvector, *ZeroCross*, to measure how much the central nervous system (CNS) is actively involved in the control of the standing balance. We report only the results in the AP direction, which showed statistical significance. A paired *t*-test was performed. Level of significance was set to p=0.05 (SPSS, v21, Chicago, IL).

RESULTS AND DISCUSSION

Surgical alignment revealed a significant decrease in the *ZeroCross* from the IDA. The *ZeroCross* in AP were Pre: 10.43±5.82 vs. Post:8.49 ± 3.78mm (*p*-value: 0.05) (Table 1, Fig. 1). The other variables did not detect the significant differences (Table 1).

CONCLUSIONS

The smaller *ZeroCross* from IDA post-surgery indicates that the surgical intervention and re-alignment allows the human postural control system to provide more active and robust balance. In other words, the CNS became more actively involved in the control of standing balance and thus the patients regain more efficient standing balance after the surgical re-alignment. The only significant change in *ZeroCross* and the insignificances from all the other measures suggest that 3 months after surgery may not be a sufficient time for ADS patients to fully recover. A long term follow-up is required. Objective motor performance measures such as *ZeroCross* from IDA will improve the evaluation and understanding of the biomechanical effects of spinal disorders on locomotion.

REFERENCES

1. Prieto et al., *IEEE Trans. Biomed. Eng.*, **43(9), pp956–966, 1996.**

2. Hur et al., *IEEE Trans Biomed Eng*, **59 pp1094–1100, 2012.**

3. Hur, *Ph.D. dissertation, University of Illinois at Urbana-Champaign*, **2010**

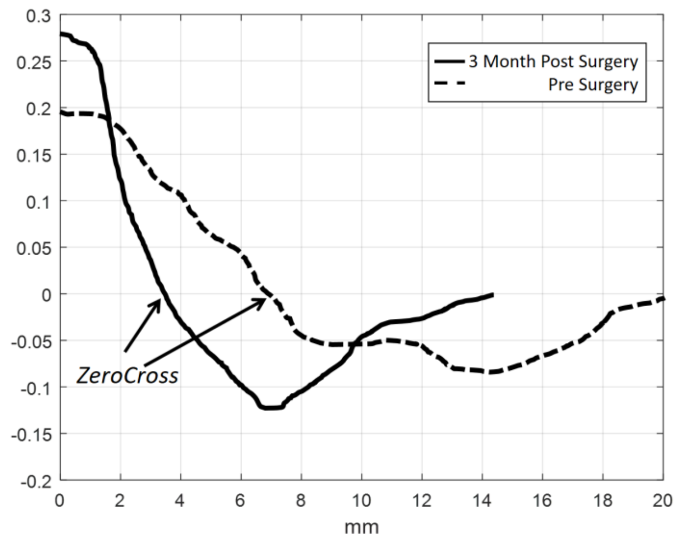

Fig. 1: A representative plot of the second eigenvector of the transition matrix for both pre-surgery (dashed) and 3 month post surgery (solid). The *ZeroCross* point happens earlier when subjects received surgery (3 Month Post).

Table 1: Required number of walking synergies pre- and post-surgery, and *t*-test results (Mean ± SD).

	Pre-surgery	Post-Surgery	*p*-value
Range	42.51 ± 18.89	39.45 ± 15.06	0.25
Mean Velocity	9.97 ± 4.02	9.62 ± 4.28	0.56
Ppeak	0.038 ± 0.038	0.040 ± 0.026	0.82
MeanDist	6.70 ± 3.41	5.93 ± 2.60	0.29
D95	16.69 ± 8.60	14.80 ± 6.34	0.29
EV2	0.985 ± 0.025	0.986 ± 0.021	0.71
Entropy	5.92 ± 0.84	5.71 ± 0.83	0.24
ZeroCross	10.43 ± 5.82	8.49 ± 3.78	**0.05**