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ORIGINAL ARTICLE

Spinal Cord Injury and Time to Instability in Seated Posture

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Abstract

Objective: To investigate seated postural control in persons with spinal cord injury (SCI) compared with age-matched controls.

Design: Cohort.

Setting: University research laboratory.

Participants: Adults (N = 36; mean age ± SD, 22.5±3.2y): 7 persons with high SCI (HI group; injury level greater than T10), 11 persons with low SCI (LI group; injury level between T10 and L4), and 18 persons with non-SCI.

Intervention: Not applicable.

Main Outcomes Measures: Participants sat on a force platform on a custom-built wooden box with their arms by their side. Postural control was quantified in several ways. Participants completed a functional reach test. The amount of postural sway was quantified by characterizing the center of pressure (COP) trajectory by determining median velocity and root mean square of the signal. In addition, the virtual time to contact to the functional boundary was quantified. Last, the instability index was determined as the ratio of the COP area to the functional boundary.

Results: There were no group differences in COP-based metrics ($P>.05$). There was no difference between SCI groups in functional reach ($P>.05$). The HI group had a smaller virtual time to contact (VTC) than the control group (.50±.20s vs .98±.24s, $P<.05$). Both SCI groups had a greater instability index than the control group, with the HI group having the largest amount of instability ($P<.05$).

Conclusions: The observations suggest that VTC analysis is appropriate to investigate seated postural control. It is proposed that including VTC of seated postural control as an outcome measure will provide novel information concerning the effectiveness of various rehabilitation approaches and/or technologies aimed at improving seated postural control in persons with SCI.

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There are more than 270,000 individuals in the United States living with a spinal cord injury (SCI), and approximately 12,000 new injuries occur each year.[1] It is well known that there is a functional limitation in mobility with SCI that negatively impacts quality of life.[2] Sitting is one of the most frequent and fundamental postures of daily life in persons with SCI.[3] Unfortunately, persons with SCI face significant challenges in maintaining a seated posture. It is believed that this dysfunction stems from impaired neural control of the involved musculature as well as decreased sensory information being transmitted to the brain.[4,5] Concerns about sitting instability are warranted, given that falls from a sitting position are common in people with SCI. Indeed, 40% of the individuals with SCI in the United States experienced falls, with 47% suffering a fall-related injury.[6,7]

Most research related to seated postural control in persons with SCI has examined standard statistics of center of pressure (COP) motion (eg, sway area, mean COP length).[4,5,8-10] Clinical measures such as the functional reach test[11] are also used routinely. An advantage of the COP metrics is that they provide a reflection of the system's neuromuscular response to the imbalances of the body's center of gravity,[12] while clinical measures do not. However, COP measures cannot access how well someone can maintain one's posture within one's stability boundary; that is, standard COP analyses do not provide a direct index of postural stability.[13]

Determination of the virtual time to contact (VTC) to the stability boundary has been proposed as a direct measure of postural instability.[14] It is maintained that postural instability occurs when the COP moves outside a stability boundary.[13] This is the case when one loses one's balance. The term "virtual" implies that individuals control their posture in such a way that it minimizes contact with the stability boundary. As such, the VTC

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approach does not require losses of stability, making it ideal for clinical populations, such as persons with SCI.

Another advantage of the VTC approach is that it incorporates the spatial and temporal features of postural sway, which provide a more topological quantification of an individual's postural strategy. Specifically, the VTC approach takes into account acceleration, velocity, and position of the COP trajectory to estimate the temporal margin to the stability boundary.[15] Examinations of time to stability boundary in standing balance have revealed that older adults,[15] persons with Parkinson's disease,[16] and persons with multiple sclerosis[17] have a smaller VTC (eg, time to losing stability) than control participants. It is maintained that the reduced VTC in these clinical populations is functionally relevant because it suggests that they have less time to recover from a postural perturbation and consequently are at a greater risk of falling. However, there has been no examination of seated postural control using this functionally relevant metric.

The purpose of this investigation was to determine whether VTC analysis of seated postural control is capable of quantifying postural instability in persons with SCI. It was predicted that individuals with SCI would have a smaller VTC compared with healthy controls and that VTC would increase with injury level in persons with SCI.

Table 1 Demographic information of participants with SCI

ID	Age (y)	Sex	Injury Level	ASIA Grade	Group
1	20	Female	L3	A	LI
2	20	Male	L1	D	LI
3	19	Female	L3	A	LI
4	20	Female	L3	A	LI
5	23	Male	T11	A	LI
6	21	Male	L4	A	LI
7	25	Female	T11	A	LI
8	20	Male	L1	C	LI
9	19	Female	L1	C	LI
10	25	Male	T11	A	LI
11	20	Female	L1	A	LI
12	27	Female	T7	A	HI
13	19	Female	T10	A	HI
14	25	Female	T10	A	HI
15	19	Male	T6	A	HI
16	22	Male	T10	A	HI
17	23	Male	T4	A	HI
18	20	Male	T7	A	HI

Abbreviation: ASIA, American Spinal Injury Association.

Methods

The experimental procedures were approved by the local institutional review committee, and all participants provided written informed consent.

Participants

A convenience sample of 36 persons (18 participants with SCI and 18 sex- and age-matched persons with non-SCI [control group]) participated in this study. The SCI group was divided into a high injury (HI; n=7; SCI at T10 and above) group and a low injury (LI; n=11; SCI between T11 and L4) group. Demographic information of participants with SCI is provided in table 1. Demographic information of the various groups is provided in table 2.

Procedures

To quantify seated postural control, participants sat with their arms by their side on a force platform,[a] which was placed on a custom-built wooden box (1.5×0.75×0.75m) and performed 3 sitting tasks. First, participants performed a functional reach test in which they reached as far as possible with their dominant hand without losing balance. Participants were instructed to keep their shoulders square to the anteroposterior axis and their nondominant hand by their side.[11] In the second task, participants leaned forward, backward, side to side, and diagonally by pivoting at the hip joints to trace a circle while leaning as far as possible without losing balance for 1 minute (fig 1). This trail allowed for the determination of the functional boundary. The last task involved participants sitting still for 30 seconds.

List of abbreviations:

COP center of pressure
HI high injury
LI low injury
RMS root mean square
SCI spinal cord injury
VTC virtual time to contact

Data analysis

Signals from the forceplate were filtered with a fourth-order low-pass Butterworth filter with an adequate cutoff frequency (5Hz). The COP was separately calculated along the anteroposterior and mediolateral axis by using the following equations:

$$\mathrm{COP}_{\mathrm{AP}} = \frac{-h \times Fx - My}{Fz}$$
$$\mathrm{COP}_{\mathrm{ML}} = \frac{-h \times Fy + Mx}{Fz} \quad (1)$$

where h is the offset between the forceplate sensors and the surface (h=20.6mm).

The functional boundary was calculated using a direct least squares fitting method[18] (see fig 1). In figure 1, the dashed line represents the actual ellipse fitted to the individuals' functional boundary while they pivoted. For the VTC calculation, a position vector of the COP on a virtual trajectory, $\tau_i(t)$, was determined for

Table 2 Demographics as a function of group

Variable	HI	LI	Control
Age (y)	23.27 (3.67)	21.36 (2.29)	22.14 (3.07)
Sex (male/female)	5/2	5/6	10/8
Sitting height (cm)	78.56 (9.57)	86.13 (10.95)	84.95 (4.65)
Weight (kg)	62.87 (13.35)	62.88 (9.79)	63.03 (8.15)
Lesion level	Above T10	T11 to L4	NA

NOTE: Values are mean (SD).
Abbreviation: NA, not applicable.