

## ORIGINAL ARTICLE

# Seated reach distance and trunk excursion accurately reflect dynamic postural control in individuals with motor-incomplete spinal cord injury

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**Study design:** To determine whether kinematic measures of reach excursion are valid measures of postural control in individuals with motor-incomplete spinal cord injury (MISCI), seated reach test (SRT; obtained from a wrist marker) values and associated trunk excursion values (obtained from a C7 marker) were compared with center of pressure excursion (COPE). Data were obtained from individuals with MISCI and from non-disabled individuals for each of four directions. To assess the reliability of these measures in subjects with MISCI, these values were collected on two separate days.

**Objective:** Dynamic seated postural control is essential for individuals who perform their daily activities from a wheelchair. Although seated reach distance is used as a proxy measure for postural control, it is unknown whether this is an accurate and reliable measure of the limits of stability in individuals with MISCI.

**Results:** In subjects with MISCI, the SRT was significantly correlated with the COPE in three directions of reaching ( $r \geq 0.71$ ), with the exception being leftward reaching. Trunk excursion was correlated with COPE in all directions ( $r \geq 0.93$ ). In non-disabled individuals, both SRT ( $r \geq 0.56$ ) and trunk excursion ( $r \geq 0.91$ ) were correlated with COPE for all directions. In individuals with MISCI, there was significant intersession agreement for both reach distance (intraclass correlation coefficient (ICC)  $\geq 0.78$ ) and trunk excursion (ICC  $\geq 0.77$ ) measured in all directions.

**Conclusions:** Although both SRT and trunk excursion are reasonable reflections of COPE, measurement of postural control based on trunk excursion has advantages for individuals who may have difficulty maintaining arm position during reaching. Reach distance is highly reliable in individuals with MISCI in all directions of reaching.

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## Introduction

Dynamic postural control, the ability to maintain balance while moving, is essential for functional mobility.<sup>1</sup> The margins of dynamic postural control, or the extremes to which an individual can reach and still maintain balance, defines his/her limits of stability (LOS). For individuals who use a wheelchair as their primary means of mobility, dynamic stability during seated reaching activities defines the workspace available to perform activities without using the arms for balance.

The seated reach test (SRT),<sup>2</sup> a test of maximal reach distance, is a clinical measure of seated postural control. In

individuals with motor-complete spinal cord injury (SCI), this test is a reliable measure in the forward-reach (FR) direction.<sup>3</sup> Maximal forward reach distance is correlated with scores on clinical tests of function in individuals with SCI<sup>4</sup> and stroke.<sup>5</sup> In spite of its clinical usefulness, there are issues that may limit the utility of the SRT as a measure of postural control in individuals with motor-incomplete SCI (MISCI).

First, notwithstanding the associations among the SRT and other clinical tests, the value of SRT assumes that it accurately reflects LOS. There may be important differences between postural control measured kinematically by the SRT and more definitive kinetic measures of LOS, such as center of pressure excursion (COPE). Although in non-disabled (ND) elderly individuals, seated reaching distance in the forward, leftward and rightward directions is correlated with COPE,<sup>6</sup> these findings may not generalize to those with

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MISCI. For example, ND individuals use various strategies during standing reach, and the extent to which reach distance reflects dynamic balance varies with the strategy used.<sup>7</sup> Many individuals with SCI use atypical movement patterns during reaching to compensate for motor impairment and trunk instability.<sup>8,9</sup> These compensatory strategies may alter the relationship between SRT and COPE.

Second, in addition to altered trunk control, impaired control of the upper extremities is likely to influence reaching distance after SCI. Although SRT is typically measured through fingertip excursion, in those with tetraplegia the inability to fully extend the wrist and fingers is problematic; however, this difficulty can be overcome by using a wrist marker. More problematic is that even in ND individuals scapular and accessory arm movements influence reaching distance, for example, reach distance can be increased by shoulder protraction.<sup>10</sup> This is an even greater challenge in individuals with impaired motor control. Differences between SCI and ND individuals have been identified in reach-related kinematics of hand and trunk movements.<sup>11</sup> Therefore, the SRT may not accurately reflect postural control in those with impaired motor function.

Third, individuals who perform their activities of daily living from a wheelchair need dynamic balance control during reaching in all directions. In SCI individuals, various aspects of FR have been reported, including test-retest reliability,<sup>3</sup> muscle activation patterns,<sup>12</sup> influence of seating,<sup>13</sup> and relationships among reach, time since injury, level of injury and functional performance measures.<sup>4</sup> FR has also been analyzed in individuals with stroke,<sup>5,14</sup> and ND individuals.<sup>6,15-17</sup> However, for a measure to be a valid representation of postural control, it must accurately reflect COPE in all directions. Different mechanisms for maintaining dynamic postural control may be used for different directions,<sup>18</sup> some of which may result in a mismatch between reach distance and dynamic balance, as has been shown in ND subjects during standing reach tests.<sup>7</sup> There is little information related to LOS in the lateral direction, and available information addresses only ND individuals.<sup>6,18</sup> Further, only a single study in ND individuals has assessed postural control in backward leaning, finding no significant correlation between backward leaning distance and COPE.<sup>6</sup>

Our objective was to determine whether the SRT is a valid and reliable measure of seated postural control in individuals with MISCI. We operationally defined seated postural control as the ability to maintain seated balance while reaching to LOS. As part of validity testing, we compared SCI data with data obtained from ND individuals. Although previous studies of SRT have focused on forward reach, it is functionally important to maintain postural stability in all directions; therefore, we tested all directions of reach. Recognizing that in individuals with impaired motor function reach may be affected by factors other than postural control, such as inability to maintain appropriate arm position, we compared kinematic LOS as measured from the wrist with that measured from the upper trunk. We compared maximal reach distance with COPE measures, with the latter being the definitive measure of LOS.

To assess reliability, we tested whether reach measures were stable over time.

## Materials and methods

### Subjects

Subjects with MISCI were recruited from the research subject volunteer database at The Miami Project to Cure Paralysis. Inclusion criteria were SCI of at least 1-year duration and injury level above T12. Exclusion criteria were current orthopedic problems or history of cardiac condition. The 10 ND subjects had no known orthopedic or neurological deficits. The study was approved by the human subjects research office of the University of Miami Miller School of Medicine, and all subjects gave written consent to participate.

To test the hypothesis that SRT accurately measures LOS in individuals with MISCI, reach distance and excursion of the upper trunk were compared with maximal COPE (see Kinetic analysis and kinematic comparisons). Data from 10 individuals with MISCI (two women, eight men; nine classified as American Spinal Injury Association (ASIA) Impairment Scale (AIS)<sup>19</sup> C, one classified as AIS D; six tetraplegic, four paraplegic; height:  $1.8 \pm 0.1$  m; age:  $46.7 \pm 5.8$  years; time since injury:  $4.3 \pm 3.4$  years) were compared with those from 10 ND subjects (four women, six men; height:  $1.7 \pm 0.1$  m; age:  $41.4 \pm 13.6$  years). No attempt was made to match subjects as there is no evidence to suggest that age or anthropometrics influences the reliability/validity of reach. However, the two groups were similar in terms of age and height.

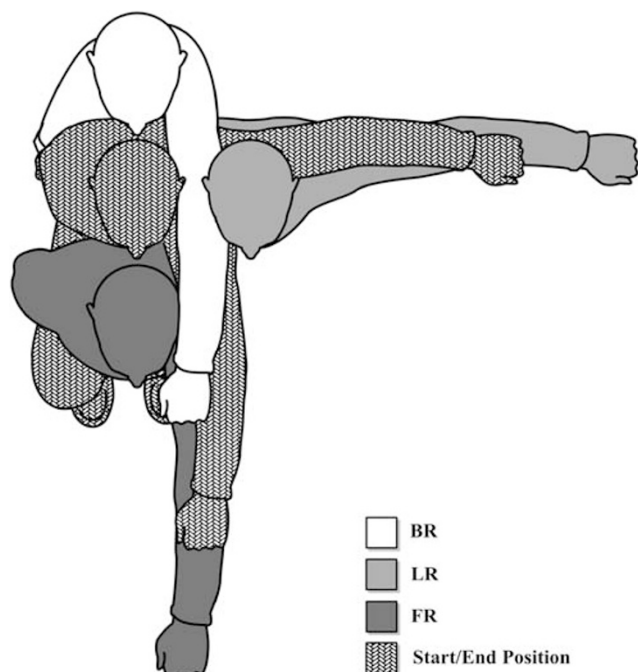
A reliability study was conducted to confirm that reliable measures of reach distance could be obtained from individuals with MISCI in each of four directions. Kinematic data were captured while seated subjects reached forward, leftward and rightward, and leaned backward (see Kinematic analysis). Thirty-two individuals (7 women, 25 men) with chronic MISCI (C3-T10; 25 classified as AIS C, 7 classified as AIS D; 23 tetraplegic, 9 paraplegic; height:  $1.8 \pm .01$  m; age:  $44.9 \pm 11.2$  years; time since injury:  $5.1 \pm 6.0$  years) participated.

### Equipment

Kinematic data were acquired through an eight-camera Peak Performance (Centennial, CO, USA) motion analysis system (60 Hz capture rate) and video record was obtained with a digital video camera (JVC TK-31680). Kinetic data were obtained from a force platform (Kistler Instrument Corp., Amherst, NY, USA) with a 0.64 cm padded cover. The kinematic, video, and kinetic data were synchronized through a TTL pulse.

### Positioning

Subjects sat with hip, knee, and ankle joints each positioned at 90°, feet flat on the floor, and the popliteal fossa approximately 2 inches from the surface edge.<sup>3</sup> The left arm was designated as the reaching arm for all directions except for the right-reach test. Subjects were instructed to hold the reaching arm at shoulder height with the hand



**Figure 1** Reach start and end positions. Illustration of start position (stippled gray figure) and maximum reach in the forward (dark gray), leftward (light gray) and backward (white) directions. Rightward reach was also tested but is not illustrated.

aimed in the direction of reach, and to rest the opposite hand on their chest. The exception was backward-reach (BR) trials, wherein subjects raised the arm to the front and leaned back as far as possible. For right-reach tests, the hand positions were reversed. Start and end positions for the different reach directions are illustrated in Figure 1. The subjects were oriented such that the forward-backward reach directions were aligned along the  $y$  axis, while left-right reach directions were aligned along the  $x$  axis. Subjects were given the instruction 'reach (or lean) as far as possible without losing your balance' after the cue 'ready, set, go.' In some individuals, motor impairment limited the ability to maintain the reaching arm at shoulder height, but they were encouraged to maintain this position to the extent possible. An assistant stood nearby to guard against falling. If balance was lost or the reaching hand contacted the table or assistant, the trial was repeated until five acceptable reaches were achieved for each direction. Subjects were allowed to rest as needed.

#### Kinematic analysis

Markers were affixed at the trochanters, anterior superior iliac spines, sacrum, T10 spinous process, acromia, lateral humeral epicondyles, ulnar styloid process (wrist marker) and C7 spinous process (trunk marker). The SRT was measured from the wrist rather than the fingertips, as many subjects with tetraplegia were unable to maintain their fingers in the extended position. Marker coordinates were filtered (Butterworth forth-order, 6 Hz low-pass filter; Peak

Motus, Peak Performance) and the average of the three longest reach values obtained in five attempts was calculated. For assessment of test-retest reliability, subjects were retested within 7–10 days after initial test.

#### Kinetic analysis and kinematic comparisons

Subjects sat on a height-adjustable table with an embedded force platform (Kistler Instrument Corp.) with a 0.64 cm padded cover. This standardized testing condition was used because chair configuration influences reaching distance in individuals with SCI.<sup>13,17</sup> Force data were collected at 600 Hz and filtered (Butterworth, 4 Hz low-pass filter; Peak Motus software). The COPE (as measured by the excursion of the center of pressure in the direction of reach) was compared with concurrently acquired SRT (as measured by excursion of the wrist marker) and trunk excursion (as measured by excursion of the C7 marker) in the corresponding direction.

#### Statistical analyses

To assess the reproducibility of kinematic measures, intraclass correlation coefficients (ICCs (3, 1); two-way, mixed-effects model) were calculated. The strength of the relationship between the SRT and COPE, and between the excursion of C7 and COPE were quantified with Pearson coefficients. Statistical analyses were performed using SPSS (Chicago, IL, USA) with significance at  $\alpha \leq 0.05$ .

## Results

#### Test-retest reliability of reaching in individuals with MISC1

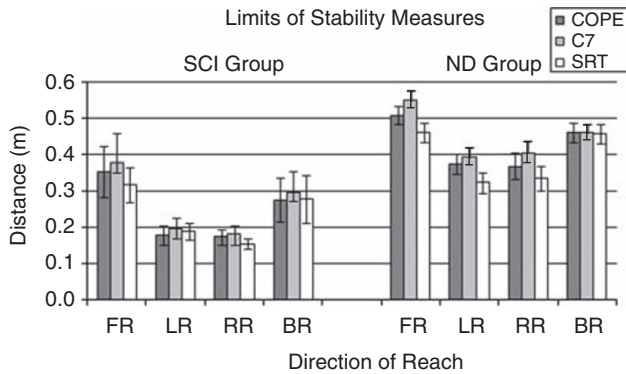
Test-retest reliability of SRT in MISC1 subjects was high for all directions of reach: forward reaching (FR) (ICC = 0.95;  $P < 0.001$ ), leftward reaching (LR) (ICC = 0.81;  $P < 0.001$ ), rightward reaching (RR) (ICC = 0.78;  $P < 0.001$ ) and backward reaching (BR) (ICC = 0.83;  $P < 0.001$ ). The test-retest reliability of trunk excursion in subjects with MISC1 was also high for all directions: FR (ICC = 0.93;  $P < 0.001$ ), LR (ICC = 0.77;  $P < 0.001$ ), RR (ICC = 0.89;  $P < 0.001$ ) and BR ( $r = 0.81$ ;  $P < 0.001$ ).

#### Relationship between wrist and trunk excursion

There was a significant difference between excursion of the wrist marker (for the SRT) and C7 marker (trunk excursion) for the FR and BR directions ( $P < 0.001$  for each), and trends toward differences in the LR and RR directions ( $P = 0.073$  and  $P = 0.057$ , respectively).

#### Relationship between kinematic and kinetic measures of LOS during seated reaching

There was a significant correlation between SRT and COPE in three of four reach directions in MISC1 subjects, (FR:  $r = 0.71$ ,  $P = 0.02$ ; right reaching (RR):  $r = 0.72$ ,  $P = 0.02$ ; BR:  $r = 0.95$ ,  $P = 0.001$ ), the exception being LR (LR:  $r = 0.61$ ,  $P = 0.061$ ). In comparison, for ND individuals correlation between SRT and COPE was significant in all four directions (FR:  $r = 0.56$ ,  $P = 0.05$ ; LR:  $r = 0.77$ ,  $P = 0.004$ ; RR:  $r = 0.78$ ,  $P = 0.004$ ; BR:  $r = 0.88$ ,  $P < 0.001$ ).



**Figure 2** Comparison of LOS measures. Mean SRT, trunk excursion and COPE ( $\pm$ s.d.) for individuals with SCI ( $n=10$ ) and ND individuals ( $n=10$ ). Abbreviations: BR, backward reaching; FR, forward reaching; LR, left reaching; RR, right reaching.

The relationship between trunk excursion and COPE was highly significant in all four directions both in MISCI subjects (FR:  $r=0.99$ ,  $P<0.001$ ; LR:  $r=0.93$ ,  $P<0.001$ ; RR:  $r=0.98$ ,  $P<0.001$ ; BR:  $r=0.97$ ,  $P<0.001$ ) and in ND individuals (FR:  $r=0.91$ ,  $P<0.001$ ; LR:  $r=0.98$ ,  $P<0.001$ ; RR:  $r=0.95$ ,  $P<0.001$ ; BR:  $r=0.94$ ,  $P<0.001$ ). Mean SRT, trunk excursion and COPE are illustrated in Figure 2.

## Discussion

Postural control during seated tasks is an early predictor of rehabilitation outcomes after stroke,<sup>20,21</sup> and is associated with improved functional task performance both in individuals with SCI<sup>4,9</sup> and in those with stroke.<sup>5,14,21</sup> The importance of dynamic sitting balance for function in wheelchair users underscores the need for valid and reliable measures of postural control. Our results indicate that the SRT provides a valid and reliable measure of postural control in individuals with MISCI in most directions of reaching, with a possible exception being LR. These results are similar to previous reports for *forward* reaching in individuals with motor-complete SCI<sup>3</sup> and stroke.<sup>5</sup> However, kinematic measures of excursion as measured from trunk appear to be more accurate than those measured from the wrist.

In individuals with MISCI and ND individuals, kinematic measures obtained from both the wrist (SRT) and the trunk (C7) during reaching are reasonable reflections of the more definitive kinetic measure of LOS, the COPE. A possible exception is the SRT in the leftward reaching direction. In our sample of individuals with MISCI, LR distance had the lowest correlation with the COPE ( $r=0.61$ ), but the probability value ( $P=0.061$ ) suggests a trend toward a relationship. A majority of people are right-hand dominant, and it is likely that most individuals with MISCI continue to perform the majority of activities with their right hands. Consequently, subjects would be more practiced in manipulating the right-side environment and reaching in rightward, and would therefore show comparatively less skill when reaching

leftward. This decreased movement toward the non-dominant side during seated reaching has been observed in ND individuals.<sup>6</sup>

In the clinical setting, wherein equipment for capture or analysis of movement data is not typically available, our results show that the SRT represents a reasonable estimate of the LOS. However, there may be advantages to using measures related to trunk (C7) excursion versus the SRT. In both MISCI and ND subjects, levels of agreement between COPE and excursion of the trunk were greater than those between COPE and SRT. This may indicate that ancillary movements, such as difficulty in maintaining full elbow extension, influence the SRT making it a less accurate reflection of LOS than measures obtained from the trunk. Therefore, for data acquired through motion capture system, measuring trunk excursion is a superior measure of LOS compared to measures obtained from the wrist. Trunk excursion measured from C7 provides a distinctive anatomical landmark and minimizes influences from arm accessory movements that could over- or under-estimate postural control, especially in those with impaired motor control.

## Limitations

All testing was completed with the feet on the floor. Since COPE measures were obtained from an instrumented seating surface and some pressure would have been distributed to the feet during FR, the COPE measured in the forward direction may not represent the actual value of excursion of the COPE. However, this measure of COPE is proportional to the actual value. Our interest was in relationships among SRT, trunk excursion and COPE; therefore, we felt this approach was preferable to raising the seating platform such that the feet did not touch the floor (a condition that subjects found difficult and anxiety provoking). We also felt that reaching with feet on the floor was a more typical condition, and one that more directly represents reaching tasks performed in daily life.

## Conclusions

Our results indicate that the SRT is a reasonably accurate reflection of LOS during reaching in both individuals with MISCI and ND individuals. In individuals with MISCI, SRT measures are stable over time. When motion capture equipment is available to record or analyze reach-related data, measurements obtained from the trunk may be preferable as these more precisely reflect COPE. However, measurements obtained from both axial and upper extremity sites provide acceptable levels of fidelity to COPE measures, with the possible exception of LR in individuals with MISCI. Further, our results show that SRT and trunk excursion provide satisfactory measures of postural control in all directions of reaching.

## Conflict of interest

The authors declare no conflict of interest.

## Acknowledgements

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