

Case Report

Midsagittal tissue bridges are associated with walking ability in incomplete spinal cord injury: A magnetic resonance imaging case series

Denise R. O'Dell^{1,2}, Kenneth A. Weber³, Jeffrey C. Berliner², James M. Elliott^{4,5,6}, Jordan R. Connor¹, David P. Cummins¹, Katherine A. Heller¹, Joshua S. Hubert¹, Megan J. Kates¹, Katarina R. Mendoza¹, Andrew C. Smith¹

¹School of Physical Therapy, Regis University, Denver, Colorado, USA, ²Craig Hospital, Englewood, Colorado, USA, ³Department of Anesthesia, Perioperative and Pain Medicine, Stanford University, Palo Alto, California, USA, ⁴Faculty of Health Sciences, The University of Sydney, Sydney, Australia, ⁵Department of Physical Therapy and Human Movement Sciences, Northwestern University Evanston, Illinois, USA, ⁶School of Health and Rehabilitation Sciences, The University of Queensland, Brisbane, Australia

Context: Following spinal cord injury (SCI), early prediction of future walking ability is difficult, due to factors such as spinal shock, sedation, impending surgery, and secondary long bone fracture. Accurate, objective biomarkers used in the acute stage of SCI would inform individualized patient management and enhance both patient/family expectations and treatment outcomes. Using magnetic resonance imaging (MRI) and specifically a midsagittal T2-weighted image, the amount of tissue bridging (measured as spared spinal cord tissue) shows potential to serve as such a biomarker. Ten participants with incomplete SCI received MRI of the spinal cord. Using the midsagittal T2-weighted image, anterior and posterior tissue bridges were calculated as the distance from cerebrospinal fluid to the damage. Then, the midsagittal tissue bridge ratio was calculated as the sum of anterior and posterior tissue bridges divided by the spinal cord diameter. Each participant also performed a 6-minute walk test, where the total distance walked was measured within six minutes.

Findings: The midsagittal tissue bridge ratio measure demonstrated a high level of inter-rater reliability (ICC = 0.90). Midsagittal tissue bridge ratios were significantly related to distance walked in six minutes ($R = 0.68$, $P = 0.03$).

Conclusion/clinical relevance: We uniquely demonstrated that midsagittal tissue bridge ratios were correlated walking ability. These preliminary findings suggest potential for this measure to be considered a prognostic biomarker of residual walking ability following SCI.

Keywords: Spinal cord injury, SCI, Magnetic resonance imaging, Tissue bridge, Walking

Introduction (context/objective)

One of the most pressing questions for patients following a spinal cord injury (SCI) is, “will I ever walk again?”¹ Indeed, walking has been frequently identified by individuals post-SCI as one of their most important health priorities.² Early prediction of walking recovery is difficult due to sedation, impending surgery, and secondary long bone fracture.³ Currently, clinicians rely mostly on physical examination.

The time-frame to establish a prognosis of residual motor function based on physical examination varies from 72 h up to 1-month post injury.³ Spinal shock, a condition characterized by complete loss of responses to external or internal stimuli of the body due to the sudden removal of descending inputs,⁴ could very well contribute to the limited prognostic value of physical examination findings alone. Furthermore, restoration of normal nerve function after SCI can take up to 2 months or even longer.⁴ Beyond isolated physical examination findings exists a need for early objective methods to effectively and

Correspondence to: Andrew C. Smith, Regis University School of Physical Therapy, 3333 Regis Boulevard, Peter Claver Hall, Suite 423D, Denver, CO 80221, USA; Ph: +1 (303) 458 4985. Email: asmith034@regis.edu

reliably predict walking recovery following SCI on a patient-by-patient basis.

A hallmark of SCI is spinal cord edema, presenting as an increased signal intensity on T₂-weighted magnetic resonance imaging (MRI).⁵ This edema develops within 72 h after SCI⁶ and impedes axonal re-growth through the injury site. The formation of a fluid-filled cavity occurs within 2 weeks and, on average, requires 4 weeks for completed edema formation, as evidenced by canine and murine weight-drop contusion models of SCI.⁷ Additionally, human work demonstrates that spinal cord edema can be detected using sagittal T₂-weighted MRI within approximately 3–4 days post injury.⁵

Imaging of the acutely injured spinal cord is traditionally used to define the dimensions that reflect the extent of the resulting edema^{1,5,6,8–15} along the superior-inferior axis. Such an approach has been used to separate patients into different prognostic categories reflecting potential for functional recovery (i.e. fair or poor)^{5,10,11} and to demonstrate a relationship with residual lower extremity motor function.^{16,17}

A recent investigation demonstrated the amount of spared spinal cord tissue bridging, measured using sagittal T₂-weighted MRI as non-edema tissue, was predictive of neurological recovery after SCI.¹⁸ This preliminary study was based on a previous manuscript involving both rodent and human SCI, demonstrating significant relationships between midsagittal tissue bridges and the clinical scores of lower extremity motor testing and ordinal measures of walking ability.¹⁹ Participants were assigned to one of four categories based on current walking ability, with “0” equating to no voluntary ambulation and “4” as “few if any deficits” in walking ability.¹⁹

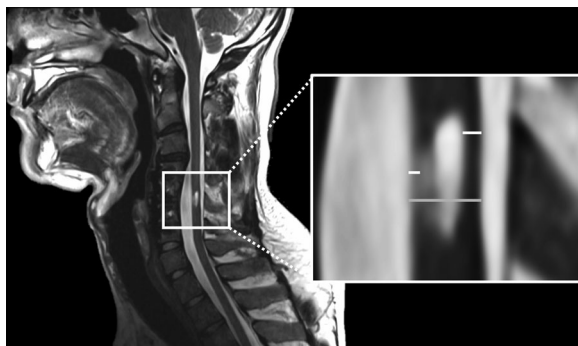


Figure 1 (Left) One representative participant's sagittal T₂-weighted image (left). (Right) Midsagittal tissue bridge ratios were calculated as the sum of the tissue bridges (white) over the cord diameter (grey).

While lower extremity motor testing and categorical data of walking ability represent a reductionist measure of residual motor function, a walking test using ratio-level data such as the Six-Minute Walk Test (6MW)²⁰ may provide a more distinguishing metric. Given the vast heterogeneity of residual motor function in persons with incomplete SCI,²¹ the 6MW test has been demonstrated to be a valid and reliable measure of walking ability in this population,²⁰ with ratio data collected as distance walked in a 6-minute time-frame.

The purpose of this case series was to establish the relationship between midsagittal tissue bridges and distance walked in 6-minutes, in 10 individuals with incomplete SCI. We hypothesized that a significant positive linear relationship would exist between tissue bridges and the 6MW distance.

Methods

This study utilized a cross-sectional case series research design, completed in a university research setting. The study was approved by Northwestern University and Regis University Institutional Review Boards. Ten individuals with incomplete SCI agreed to participate, provided written and verbal informed consent, and completed the study (1 female, average age = 42 years old \pm 13).

MRI measures: midsagittal tissue bridge ratio

Sagittal T₂-weighted imaging of the cervical spinal cord was performed using a 3.0 Tesla Prisma magnetic resonance (MR) scanner equipped with a 64-channel head/neck coil (Siemens, Erlangen, Germany). Sagittal T₂-weighted structural imaging of the cervical spine and spinal cord damage site was acquired using a 2D turbo spin echo sequence using 24 consecutive slices (TR = 2300 ms, TE = 106 ms, flip angle = 88°, phase encoding direction: right to left, slice thickness = 2.0 mm, acquisition matrix = 512 \times 512). Spinal cord sagittal T₂-weighted MRI data were analyzed offline using OsiriX image processing software (Pixmeo, Geneva, Switzerland). Using the midsagittal T₂-weighted image, anterior and posterior tissue bridges were calculated as the distance from cerebrospinal fluid to the edema (see Fig. 1). Then, the midsagittal tissue bridge ratio was calculated as the sum of anterior and posterior tissue bridges divided by the spinal cord diameter (see Fig. 1).

Six-minute walk test

Participants performed overground 6-minute walk tests, where the total distance walked was measured within six

timed minutes.²⁰ Each participant was permitted the use of assistive devices or braces as necessary to walk at a normal, self-selected pace.

Statistical analyses

All statistical analyses of the data were performed using IBM SPSS (Version 23, Armonk, NY, USA). An intra-class correlation coefficient (ICC_{2,1}) was used to test the inter-rater reliability of the midsagittal tissue bridge ratio measure across seven different raters. A Pearson correlation was selected to examine the linear relationship between midsagittal tissue bridge ratios and distance walked in 6 minutes. A P value of <0.05 was considered statistically significant.

Results

The midsagittal tissue bridge ratio measure demonstrated a high level of inter-rater reliability (ICC_{2,1} = 0.90). Midsagittal tissue bridge ratios were significantly related to distance walked in six minutes ($R = 0.68$, $P = 0.03$, see Fig. 2).

Discussion

In this case series, we uniquely demonstrated that midsagittal tissue bridge ratios were significantly related to a reliable, and valid, discriminative ratio-level measure of walking ability of 10 participants with incomplete SCI. Our findings are in accordance with previous literature that examined this sagittal T₂-weighted MRI measure and related to functional outcomes following SCI.^{18,19} In this present study, we used a continuous variable for our primary outcome, the distance walked within a six-minute time-frame, which provides a more distinguishing measure of an individual's locomotor ability. While past studies used discrete categorical outcome measures (i.e. motor scores and four categories of walking ability) and related to midsagittal tissue

bridges,^{18,19} our study further expanded upon the predictive potential of this MRI measure to a more discriminative test of walking.

While past correlations using sagittal T₂-weighted MRI measures and locomotor abilities have been poor,²² newer studies affirm the importance of these sagittal imaging measures for prognosis of residual motor function.^{8,18} Spinal cord edema measurement in other planes, such as the axial plane, may also augment prediction of walking and motor recovery after SCI.^{16,17} As imaging methodology continues to improve, more sophisticated edema measurement techniques, such as machine learning driven approaches, may show potential to better inform and enhance our clinical prognostic abilities.

Limitations

One inherent limitation with a cases series is the smaller sample size. Our future research aims to investigate the prognostic potential of midsagittal tissue bridge measures in a larger dataset of persons with SCI. A second limitation is the subjective nature of this manual measure. However, we found a high level of inter-rater reliability, suggesting this measure is consistent across raters and therefore potentially clinically relevant and useful. A third limitation is that due to the unavailability of data, we did not include other MR sequences or contrasts in this research. Previous literature suggests that short tau inversion recovery (STIR) MRI, in particular, may be more sensitive than T₂-weighted MRI in detecting spinal cord lesions in patients with multiple sclerosis, cervical myelopathy, and traumatic SCI.^{23–28}

Conclusion

In this present case series involving 10 participants with incomplete SCI, we uniquely demonstrate that midsagittal tissue bridge ratios were correlated with the ratio-level measure of distance walked in 6 min. These preliminary findings suggest potential for this measure to be considered a prognostic biomarker of residual walking ability following SCI. Improving early and accurate prediction of future locomotor function after SCI is of utmost importance to all stakeholders, including patients, families, and the healthcare team. Early prediction of functional recovery will improve the clinical management and individualized intervention of individuals with SCI. Further research is warranted to apply these methods to a larger dataset in the acute stage of SCI, in order to explore and establish the predictive value of midsagittal tissue bridge measures.

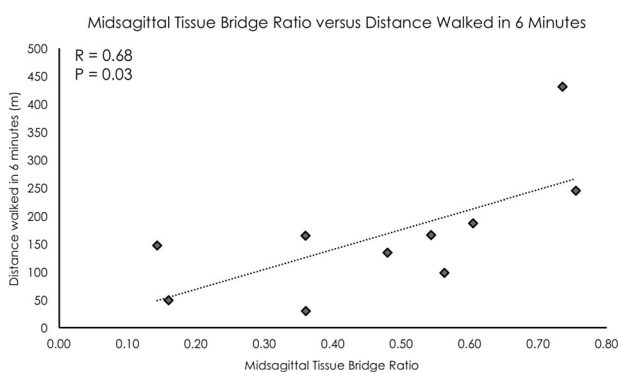


Figure 2 A significant positive linear relationship was found between midsagittal tissue bridge ratios and distance walked in 6 min ($R = 0.68$, $P = 0.03$). Participants were allowed to use assistive devices and orthoses as necessary.

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Conflicts of interest The authors have no conflicts of interest to disclose.

ORCID

Kenneth A. Weber  <http://orcid.org/0000-0002-0916-9174>

James M. Elliott  <http://orcid.org/0000-0002-8890-6012>

David P. Cummins  <http://orcid.org/0000-0002-4416-2541>

Katherine A. Heller  <http://orcid.org/0000-0002-0317-436X>

Andrew C. Smith  <http://orcid.org/0000-0001-5020-8094>

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