Cervical Cord-Canal Mismatch: A New Method for Identifying Predisposition to Spinal Cord Injury

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Key words
- Canal stenosis
- Cervical spine
- Congenital
- Degenerative cervical myelopathy
- Developmental
- Narrow canal
- Neurapraxia
- Risk factor
- Spinal cord compression
- Stinger
- Traumatic spine cord injury

Abbreviations and Acronyms
APD: Anterior-posterior diameter
CSS: Congenital cervical spinal stenosis
DCM: Degenerative cervical myelopathy
MRI: Magnetic resonance imaging
SAC: Space available for the cord
SCI: Spinal cord injury
SCOR: Spinal cord occupation ratio
TPR: Torg-Pavlov ratio

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The risk for spinal cord injuries (SCIs) ranging from devastating traumatic injuries, compression because of degenerative pathology, and neurapraxia is increased in patients with congenital spinal stenosis. Classical diagnostic criteria include an absolute anteroposterior diameter of <12–13 mm or a Torg-Pavlov ratio of <0.80–0.82; however, these factors do not take into account the size of the spinal cord, which varies across patients, independent of canal size. Recent large magnetic resonance imaging studies of population cohorts have allowed newer methods to emerge that account for both cord and canal size by measuring a spinal cord occupation ratio (SCOR). A SCOR defined as ≥70% on midsagittal imaging or ≥80% on axial imaging appears to be an effective method of identifying cord-canal mismatch, but requires further validation. Cord-canal size mismatch predisposes patients to SCI because of 1) less space within the canal lowering the amount of degenerative changes needed for cord compression, and 2) less cerebrospinal fluid surrounding the spinal cord decreasing the ability to absorb kinetic forces directed at the spine. Patients with cord-canal mismatch have been reported to be at a substantially higher risk of traumatic SCI, and present with degenerative cervical myelopathy at a younger age than patients without cord-canal mismatch. However, neurologic outcome after SCI has occurred does not appear to be different in patients with or without a cord-canal mismatch. Recognition that canal and cord size are both factors which predispose to SCI supports that cord-canal size mismatch rather than a narrow cervical canal in isolation should be viewed as the underlying mechanism predisposing to SCI.

INTRODUCTION

Spinal cord injuries (SCIs) have a devastating impact on neurologic function and consequently can tremendously reduce the quality of life of affected individuals. Although substantial injuries to the cervical spinal cord typically occur because of high impact forces, such as from falls or motor vehicle accidents,[1] more progressive and milder forms of SCI are the most common type of injury and occur from age-related wear, referred to as degenerative cervical myelopathy (DCM).[2] Although the risk profiles for these types of injuries differ, it has been recognized that a common predisposition to traumatic SCIs, DCM, and neurapraxia is what has been classically referred to as congenital or developmental cervical stenosis.[2,3] This designation simply refers to a narrow anatomic cervical canal. Indeed, classical diagnostic criteria have suggested that a radiologic spinal canal diameter of 12–13 mm[4,5] or a Torg-Pavlov ratio (TPR) of 0.80–0.82[3,6] is indicative of canal stenosis; unfortunately, neither method takes into account the size of the spinal cord (**Figure 1**). However, recent magnetic resonance imaging (MRI) studies of cervical spines have shown that there are considerable variations in the size of the spinal cord,[7-9] therefore supporting the need to rethink these classical diagnostic criteria. More recent methods have looked at the subaxial space available for the cord (SAC) or assessed the spinal cord occupation ratio (SCOR), which evaluates the size of the spinal cord within the spinal canal and DCM.[7,10-14] In contrast with the classical diagnostic criteria, the premise for using the SCOR is based on a spinal cord-canal size mismatch. To support this pathophysiologic perspective, we first review current MRI size parameters for the cord and canal. Thereafter, through discussion of the rationale of SCOR measurements and recent findings, it is proposed that cord-canal mismatch be used as a diagnostic criterion for identifying individuals at risk for spinal cord compression and injury.

ANATOMIC MRI MEASUREMENTS OF THE CERVICAL SPINAL CORD AND CANAL

There have been numerous studies that have examined the size of the canal diameter using radiographs, computed tomography scans, and cadaver studies,[4,5,15,16] but there are few studies that have examined the anatomic measurements of the cervical spinal cord (**Table 1**). This is

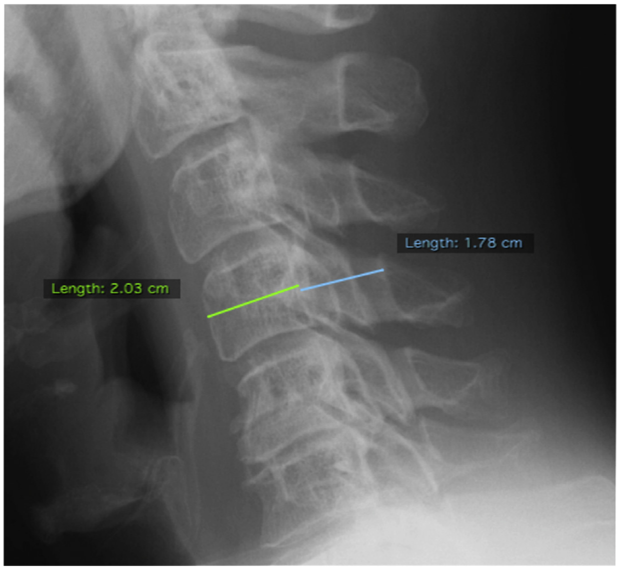

Figure 1. Anterior-posterior spinal canal and midvertebral diameter measurements. The spinal canal diameter in this patient is 1.78 cm and the Torg-Pavlov ratio (canal-body ratio) is 0.877 (1.78 cm/2.03 cm).

partially because the spinal cord is best visualized through MRI, which is costly. When attempting to compare the findings between these studies, variations in postmortem versus in vivo measurements, for example, complicate the appraisal of findings across different studies. Postmortem studies are susceptible to fixation and atrophy bias, likely underestimating the size measurements.[9] On the other hand, in vivo imaging studies are limited by the resolution of the imaging modality. One such example was highlighted by a report that the T1 axial cord area is higher than the T2 cord area in the same patient.[17]

The most widely used cervical cord and canal measurement parameters are at vertebral, intervertebral, or cord level, and include the cross-sectional anterior-posterior diameter (APD), lateral or transverse diameter, and corresponding area. The most extensive analysis of cord morphology showed that the average T2-weighted image APD canal diameter is between 12.7 and 14.4 mm and between 11 and 13.6 mm in men in their 20s and 70s, respectively, and between 12.6 and 14.3 mm and between 10.8 and 13.5 mm in women in their 20s and 70s, respectively.[7] The smallest average canal size was typically present at the C5-6 disk level, regardless of age or sex. Another study showed that in extension, the C4-6 canal region is smallest, and disk bulging and ligamentum flavum enlargement are most pronounced.[18] In terms of the average spinal cord diameter, a size between 5.7 and 7.0 mm and between 5.4 and 6.8 mm in men in their 20s and 70s, respectively, and between 5.5 and 6.7 mm and between 5.3 and 6.7 mm in women in their 20s and 70s has been reported,[7] respectively. However, it is noteworthy that the spinal cord APD is greatest near the craniocervical junction and slowly decreases in size toward the cervicothoracic junction in both men and women,[7,18] and remains relatively constant in size during flexion and extension.[18]

Despite differences between postmortem and in vivo imaging measures, studies have shown parallel or complementary findings in several domains. Large postmortem and in vivo computed tomography/MRI studies have shown that men have significantly larger baseline cervical cord and canal parameters than women.[4,7,8,17,19] MRI studies have also found that height is positively correlated with cervical cord area in both men and women[8] and that cervical spinal cord volume is larger in men, decreases with age, and increases with height and body weight.[20]

Differences in canal and cord size may also vary based on ethnic factors, but such differences have not been fully explored. In a large postmortem study, there was no significant difference found between the cervical canals of black versus white U.S. adults.[4] Such factors along with potential difference in degenerative patterns may have implications on the risk for spinal cord compression. Indeed, in a large South African study on cadavers, native African women and men were found to have, both as subgroups and as a whole, statistically significant lower rates of individual cervical vertebrae osteophytosis than white women and men.[21]

SCOR to Identify Cord-Canal Mismatch

Although absolute spinal canal measurements and TPR provide ways to estimate the presence of a narrow canal, the lack of consideration for the size of the spinal cord limits the validity of such methods from a diagnostic perspective. Indeed, in a secondary analysis of a Japanese cohort,[7] it was shown that cord size varies independently of the canal size, and that a large cord size can also be a risk for cord compression.[22] Furthermore, studies have shown that the SAC is superior to the TPR in assessing the risk for neurapraxia,[13] and the TPR poorly correlates to the SAC.[23] Recognizing that the SAC, the spinal cord size, and the spinal canal diameter all are important factors to consider, suggests that the basis of risk for spinal cord compression should be based on a principal of cord-canal size mismatch and not canal stenosis in isolation. Recent appreciation of these factors has led to the development of SCORs to assess for this cord-canal mismatch.

The SCOR is a measure that estimates the amount of spinal canal space that is occupied by the spinal cord, and it has been recently used by a number of authors as a diagnostic criterion for congenital cervical stenosis[7,10,11] (Figure 2). The computation of SCORs became feasible after the recent publication of normal spinal canal and cord size parameters using MRI.[7-9] Although the measure takes into account the size of both the canal and cord, there is greater variability in canal size compared with spinal cord; therefore, the SCOR is likely to be influenced by canal size to a larger extent (Figure 3). The largest MRI study[7] recently showed that the 2 SD upper limit of the SCOR was approximately 72% at C5 (measured as the anteroposterior diameter of the cord divided by the anteroposterior