

Resolving the anatomic variability of the human cervical spinal cord: a solution to facilitate advanced neural imaging.

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Target audience. Scientists and clinicians interested in spinal cord diffusion tensor imaging and template-based group analysis.

Purpose. The current paradigm for analyzing spinal cord MRI data is to infer the position of the nerve rootlets (NR) from the location of the vertebral bodies (VB).¹ This approach assumes that the relative location between the NR and the VB is the same across individuals and age, however recent studies suggested that this is not the case.² The objective of this work is to demonstrate the variability of NR location across individuals and to predict it based on subject-specific regressors (neck length, height, VB size and location, age). Results of this study directly impact how multiparametric MRI studies of the human spinal cord should be interpreted to accurately account for the neuroanatomical substrate that underlies the MRI data.

Methods. 20 healthy volunteers (35% male, mean age = 30.5 years, range = 19-52 years) were scanned on a 3T GE MR system using an 8-channel coil. T2-weighted acquisition was optimized to visualize NR emerging from the cervical spinal cord. Parameters were: FIESTA-C sequence; 512x512, NEX 1.0, FOV 200mm, voxel size 0.4x0.4x0.3 mm (no interpolation). Expert identification of VB and C3 to C8 NR position was performed using 3D Slicer. After reconstructing the spinal cord centerline, the distance of VB and NR from the ponto-medullary junction was measured. To predict the position of NR across individuals, we used a linear least-squares regression approach with input variables: neck length, total body height and the midpoint location of vertebral bodies C3 to C7 along the spinal cord axis. To evaluate these predictors we used a simple form of leave-one-out cross-validation.

Results. Top figure shows the distribution of VB (light beige) and NR (colored) for each subject. Bottom figure shows the scaled relative distance of the C7 NR (red bars) from the C6 (upper light brown shaded area) and C7 (lower light brown shaded area) VB. When we visualize an individual person's cervical spine MRI, we tend to hold the vertebral bodies constant. This figure illustrates that the position of the 7th cervical spinal cord segment varies relative to the position of the vertebral body across a cohort of individuals. If one were to assume that the C7 spinal cord segments are 1 vertebral body length rostral to the C7 body—which is currently the standard procedure—, then one would capture 44% of the corresponding spinal segments.

Discussion. In this work we provide a novel, quantitative solution to deal with the anatomical variability of the human cervical cord. For the first time, we report a population distribution of the segmental anatomy of the cervical spine that has direct implications for the interpretation of advanced imaging studies most often conducted across groups of subjects. We demonstrate that significant variation exists in the rostral-caudal position of spinal cord segments between individuals and that a combination of variables (subject neck length, body height and the position of vertebral bodies relative to the PMJ) can be used to predict the position of a given spinal segment. Accounting for this variation will be paramount to accurate interpretation of the neuro-anatomical origin of acquired MR signals in future imaging studies. This especially holds true for functional MRI studies that are challenging due to the low sensitivity for studying single subjects (notably due to low signal-to-noise ratio and high physiological noise), and by the intrinsic variability of spinal rootlet locations that hamper the use of grouped data.

References.

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