Quantification of Spinal Cord Atrophy via an Active Surface Model

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Introduction

Spinal cord atrophy is of interest for multiple sclerosis (MS) studies because it is sensitive to disability in MS patients and can be detected even in early disease. We aim to provide measurements of atrophy along the cord by extracting the cord surface in a continuous parameterised form, computing its medial axis, and defining cross-sections orthogonal to this medial axis. Measurements of those cross-sections area along the nerve are then available to locate and quantify potential atrophy.

Methods

Inversion recovery gradient echo images were acquired in the sagittal plane with 256x256x60, 0.98x0.98x1mm^3. Images are pre-processed using a non-linear edge-preserving diffusion filter, to reduce noise and enhance edges [1].

A B-Spline active surface is then embedded in the image. The model is parametric and defined as presented in [2]. A mesh of control points define the entire surface. An energy is associated with the surface, whose minimum corresponds to the desired location [2,3] (the boundaries of the spinal cord). This energy is a sum of a gradient term that attracts the surface to structure boundaries, and an internal term that guarantees the surface smoothness.

The surface is iteratively optimised by sequential optimisation of the set of control points, namely the *greedy algorithm* [4]. Because this optimisation scheme converges to local minima of the energy function, it is important to provide a good initialisation of the surface. Our model is interactively initialised as follows: through a graphic interface, the user choses a set of landmarks in the center of axial sections along the cervical cord. The first landmark is set at the foramen magnum, the last landmark at the base of the 7th cervical vertebra, and two landmarks per vertebra are set. Each landmark is the center of a set of control points located on a circular section of fixed diameter (11mm). This defines the initial surface as a pseudo-cylinder of constant radius that roughly approximates the cord shape. After optimisation, a parameterisation $S(r,s)$ of the cord surface is obtained, with r an axial parameter and s a longitudinal parameter, both in the interval $[0;1]$.

A cord medial axis A is then defined by the following: $A(s)=\int S(r,s)dr$. With this definition, the position of the medial axis is defined for every value of s and we can compute the plane $P(s)$ orthogonal to A at s.

Orthogonal sections $O(s)$ of the cord at parameter s are then defined as the intersection of the plane orthogonal to the axis and the surface itself: $O(r,s)=P(s)\cap S(r,s)$. This intersection is computed with a search of the zero crossings of the plane equation on the surface S. The medial axis is sampled with a step ds (e.g. 0.01) and one cross-section is computed at every step. Each cross-section is stored as a set of points on the surface, and a center (the corresponding points on the medial axis). The area of those cross section is then straightforward to compute. Eventually, the orthogonal cross-section areas along the axis, between the foramen magnum and the 7th cervical vertebra. are available for statistics and can be plotted against parameter s, as shown in figure 1.

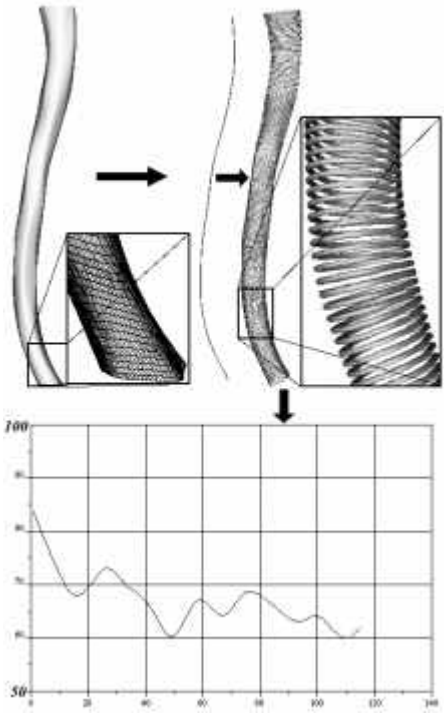

figure 1

Results and discussion

The surface optimisation is shown to provide an accurate segmentation of the cord. Manual in-slice extraction methods are intensity based and require intensity correction pre-processing techniques to guarantee an almost constant intensity on the cord boundaries. Because our automatic extraction of the surface is gradient based, it does not require this intensity correction step.

The method results in a parametric C^2-continuous representation, which provides an implicit inter-slice interpolation and allows for analytical differential measurements on the surface.

The computation of orthogonal cross-sections is more precise than usual in-slice measurements because slices are not orthogonal to the cord and measurements would depend strongly on the orientation of the cord.

With a sampling rate of one cross section every 0.7mm along the axis, one can proceed to precise atrophy localisation and statistics.

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