Semi-automatic 3D Segmentation and CNR Measurement of Mn2+ Enhanced Optical Nerve in Adult Rats

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Introduction: The purpose of this project was to develop an objective method of calculating Contrast-to-Noise Ratio (CNR) profiles from 3D MRI data of the Mn^{2+} enhanced optic nerve based on minimal user intervention. We present a semi-automatic procedure where the Mn^{2+} enhanced optic nerve is segmented and the CNR profile is calculated using one seed point.

Materials and Methods: 3D MRI datasets from adult inbred Fisher rats (N = 31) were obtained at 2.35T (Bruker Biospec Avance DBX-100) using a T1-weigthed 3D low flip angle gradient echo sequence (FLASH) with TR = 15 msec, TE = 4.2 msec, flipangle = 25° with an acquisition matrix 256x256x128 voxels giving a resolution of 195x195x156 μm^3. The MRI image acquisition and experimental protocol is described in detail by Thuen et. al[1]. The data analysis and implementation was done using Matlab® R14 SP2 which included the image processing toolbox.

Data analysis: Segmentation of the nerve was done in 3 steps. **Step1:** A global threshold was set by histogram analysis of a region around the non-enhanced optical pathway. The non-enhanced signal was thresholded using an iterative procedure described by Gonzalez and Woods[2]. The MR signal follows a Rice distribution, but for large offsets the normal distribution is a good approximation. A normal distribution was fitted to the non-enhanced signal and the global threshold level was set to 2 – 3 standard deviations above the mean. **Step 2:** Segmentation of the thresholded image volume was done by 6-connected region growing and the Mn^{2+} enhanced nerve was identified by using a manually chosen seed point. This left the optical nerve, but also larger structures (e.g. eye and part of brain) connected to the nerve. **Step 3:** Removal of large structures was done by morphological top-hat transformation using a ball-shaped structuring element slightly larger than the nerve diameter.

Tracing of the nerve centre was done by placing two boxes (3x3x3 and 7x7x7voxels) centred on the seed point after step 2. The centre of the nerve was calculated inside the innermost box, and the density was calculated inside the outermost box. Until both ends were detected, the boxes were slid along the nerve until the density reached zero (end of Mn^{2+} enhancement) or a predefined critical value (~0.7) indicating the nerve entering a larger structure. The centre of the nerve was smoothed using a sliding mean (box size 5) and re-sampled in a user defined spatial resolution. An example of a segmented nerve and the traced centre is seen in figure 1.

Using the coordinates of the centre of the nerve (which were a subset of the top-hat transformed nerve), planes perpendicular to the nerve were defined and the grey values on them estimated using trilinear interpolation. The mean signal of the nerve in each plane was calculated in a radius of 0.6 mm from the centre of the nerve.

A model of the non-enhanced nerve was used to calculate the non-enhanced signal. Based on measurements of 10 animals, a normalized linear model of the first 6 mm of the optic nerve was developed, using linear regression. The regression model can be written as *Relative intensity = 1.029 – 0.030xPosition (mm)* ($R^2 = 0.904$ and $p < 0.001$ for both coefficients using SPSS 13.0). The signal from the non-enhanced nerve was calculated using the model and a measurement of the non-enhanced signal at position ~0.2 mm, by fitting a normal distribution to the histogram, giving the mean signal.

CNR defined as $CNR = 0.655(S_{Mn}+S_0)/SD_{Air}$ was calculated at each point along the nerve, where S_{Mn} was the manganese enhanced signal, S_0 was the non-enhanced signal and SD_{Air} was the mean value of SD of two ROI's in air.

Results and discussion:

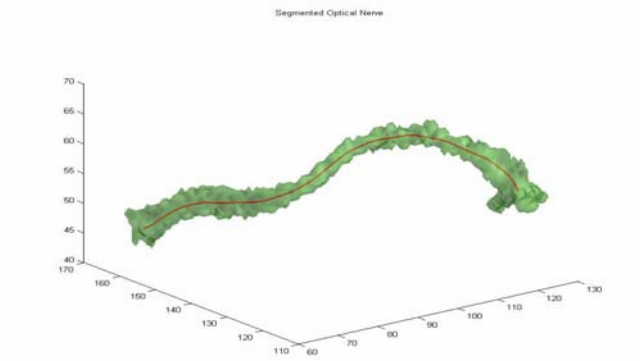

Figure 1: *Segmented optical nerve with traced centre (red).*

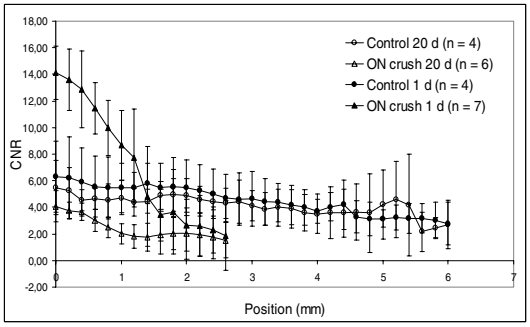

Figure 2: *CNR profiles of Mn^{2+} enhanced optical nerve with and without crush at ~2mm. The error bars represent 95 % confidence interval of the mean values.*

CNR profiles were computed (figure 2) on the same dataset used by Thuen et. al[1]. The CNR profiles obtained with the semiautomatic procedure gives profiles detecting the crush site at ~2 mm on animals with nerve injury, and the whole profile for control group. This is comparable with the findings reported by Thuen. et. al.

Conclusion: We have presented robust and objective a method of calculating the CNR profile of the Mn^{2+} enhanced optical nerve based on objective measurements and few user interactions. The method traces the centre of nerve, segments the nerve from the eye and calculate the CNR profile with a user defined spatial resolution. The method will be used for detecting small changes in the manganese profile in the nerves quantitatively before and after mechanical injury in the study of CNS regeneration in vivo. Even though the method is dedicated for a specific problem it has a general potential.

References:

1 Thuen et. al. Manganese-Enhanced MRI of the Optic Visual Pathway and Optic Nerve Injury in Adult Rats. J Magn Reson Imaging. 2005 Oct;22(4):492-500.
2 Gonzalez, R.C., Woods, R.E. Digital Image Processing, 2nd ed. 2002, Prentice Hall.