Calculation of optic nerve dimensions using Gaussian fitting of MR images

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Introduction:

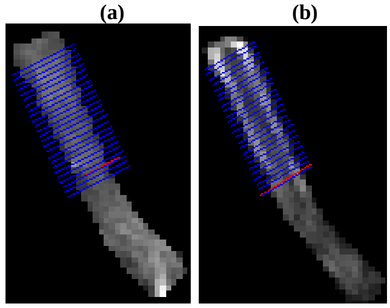
Imaging of the optic nerve using MRI is particularly challenging due to its small size and the effect of the surrounding optic nerve sheath and cerebrospinal fluid (CSF) [1]. Qualitative imaging is often used in the diagnosis of optic neuritis related to multiple sclerosis. Quantitative imaging is useful in tracking changes following an attack of optic neuritis. The optic nerve cross-sectional area in normal subjects was found between 5.7-10.6 mm^2 using a high-contrast lipid stain, paraphenylene-diamine (PPD) and a video image measurement system for humans aged between 31-86 [2]. A serial MRI study in optic neuritis using a Short-Echo fast FLuid-Attenuated Inversion Recovery (sTE fFLAIR) sequence and semi-automated image processing reported a mean area of 11.3 mm^2 compared with 12.8 mm^2 for healthy contralateral optic nerves, one year after an attack of optic neuritis [3]. The aim of this study was to develop a program to accurately calculate the optic nerve area and volume using Gaussian fitting of the acquired MR images. The program will be used in a new study of optic neuritis on 1.5T and 3.0T MR systems with both T1- and T2-weighted 3D Spectral Presaturation Inversion Recovery (SPIR) sequences and much shorter scan times compared to a previously reported study [3].

Methods:

A 3T MR system (Intera, Philips, NL) with an 8-channel SENSE head coil was used to acquire T1W and T2W 3D gradient echo SPIR images on an oblique axial slice containing the optic nerves. The scan parameters were: T1W: TR/TE = 25/2.7 ms, FA = 35^0, NEX = 2; T2W: TR/TE = 2000/140 ms, FA = 90^0, NEX = 1; both sequences had similar voxel sizes = 0.75 x 0.75 x 0.75 mm^3, FOV = 130 x 130 x 25 mm^3, matrix = 176 x 176, 33 slices. Preliminary images were acquired from four healthy volunteers (age 20-55, 2F, 2M) with normal vision. The measurement program was written using Matlab 7.0 (The MathWorks Inc., MA). First, a mask for both optic nerves was carefully selected and used to select out all the slices containing the optic nerves (see Fig.1). A set of intensity line profiles was then taken across the cross-section of the optic nerve. Since the optic nerves curve towards the centre where they join at the optic chiasm, the line profiles were chosen for the straight, intra-orbital portion only. It was found that each volunteer had a slightly different angle of curvature of the optic nerve. A fixed length of 18.5 mm (Fig.1 illustrates the 25 line profiles) was chosen at the top portion closer to the eyeball. Some volunteers had a slightly larger diameter of the optic nerve at the top near the retina. Hence the first line was chosen at a position with a consistent diameter. The line profiles were spaced by a distance of 1 pixel. A mean line profile, $m(x)$, was calculated for each optic nerve. Then, a Gaussian function with either single peak (Eq.1) or three peaks (Eq.1) was used to fit the mean line profile, $m(x)$. A single peak, G_1, was used to fit the T1W images which had a similar contrast across the mask (Fig.1a); whereas a three peak function, G_3, was used to fit the T2W images which had a brighter edge on both sides (Fig.1b) with the chosen sequence.

Fig. 1: A mask for an optic nerve with a set of line profiles drawn on (a) T1W image, (b) T2W image, acquired from the same volunteer.

(a) **(b)**



$$G_1 = a_1 \exp[-(\frac{x-b_1}{c_1})^2] \qquad (1)$$

$$G_3 = a_1 exp[-(\frac{x-b_1}{c_1})^2] + a_2 exp[-(\frac{x-b_2}{c_2})^2] + a_3 exp[-(\frac{x-b_3}{c_3})^2] \qquad (2)$$

where a is amplitude, b is centroid location, c is peak width, and the subscripts $1, 2, 3$ denote the three peaks. The diameter of the optic nerve was calculated using the Full Width at Half Maximum (FWHM) of the peak c_1 in Eq.1 or the middle peak in Eq.2:

$$\text{Diameter of the optic nerve} \approx \text{FWHM of middle peak} = 2\sqrt{2\ln(2)} \times c \qquad (3)$$

The diameter was calculated for each slice and a mean value was obtained, which was used to calculate the mean cross-sectional area of the optic nerve using the formula: $area = \pi*(mean\ diameter/2)^2$. The volume of the optic nerve with the chosen length was calculated by considering a cylindrical shape using formula: $volume = area*length$. The measurement was repeated three times for each data set to get a mean value. Then an intra-subject mean value and standard deviation was calculated for all volunteers.

Results:

Fig.2a shows a typical surface plot of the set of line profiles in Fig.1b; Fig.2b is the mean intensity line profile. The Gaussian fitted function (red) was overlaid on Fig.2b with the measurement (blue), which showed a close fit for all volunteers. The calculated mean diameter, area and volume from all volunteers are recorded in Table 1. The mean diameter and area of the optic nerve on T2W images fall within the range reported in reference [2].

Fig.2a: Surface plot of a set of intensity line profiles.

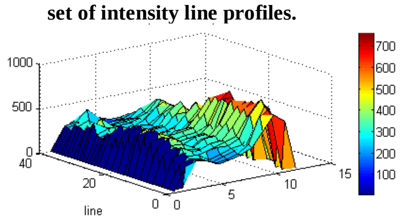
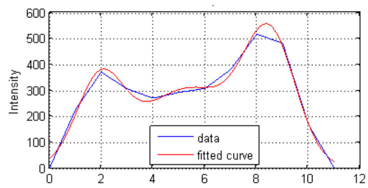


Fig.2b: Mean intensity line profile from measurement and Gaussian fit.



Discussion:

The larger diameter on T1W images includes not only the nerve but also the sheath as well as a thin layer of CSF surrounding the optic nerve. This detailed layer structure is currently under investigation using a T2W FLAIR sequence with a range of TI times. A typical length of the optic nerve is about 50 mm [4]. The chosen length does not give the full volume of the optic nerve. However, by using a fixed length for all subjects and a standardized measurement using Gaussian fitting, the program should be useful for comparing diseased and healthy optic nerves instead of manual measurement. However, lesions may occur in any part of the optic nerve, hence a separate measurement and comparison may be necessary for the curved portion of the optic nerve in the optic canal and intracranial portion.

Table 1: Mean values of the diameter, area and volume of the optic nerve using 18.5 mm length.

	T1W images	T2W images
Diameter (mm)	5.1 ± 0.4	3.1 ± 0.4
Area (mm^2)	20.7 ± 3.3	7.6 ± 1.8
Volume (mm^3)	380.6 ± 63.2	139.1 ± 33.6

Conclusions:

A fast and consistent program has been developed to calculate the diameter, area and volume of the optic nerve from MR images. This study also shows that T2W images are suitable for measuring the actual optic nerve's dimension; whereas T1W images can be used to measure the optic nerve and the sheath and CSF surrounding the nerve.

References: [1]Barker. J.Neurological Sci.2000;172:S13-16. [2]Johnson et.al. Age 1987;10:5-9. [3]Hickman et.al. Brain 2004;127:2498-2505. [4] Walsh & Hoyt. Clinical Neuro-Ophthalmology.