Indices for Probabilistic Tractography through regions of fibre crossing

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Introduction

In recent years many algorithms for fibre tracking have been introduced in the literature (see Parker[1] for a review). The earliest algorithms assumed a one-to-one mapping between points within the brain using directional information derived from the tensor model of diffusion processes. More recent algorithms have attempted to account for the noise present in the data for example by bootstrapping across multiple acquisitions, or using a Bayesian technique to estimate the likelihood of model parameters in each voxel given the data. All such approaches are able to produce a probabilistic index of connectivity between points. In parallel, many efforts have been made to more accurately estimate the diffusion parameters within a voxel; in particular in order to account for partial volume effects within regions of crossing fibres. Conventionally, partial volume due to fibre crossing has been considered by tractography algorithms as a further source of noise in the data. Where information about fibre heterogeneity is available, the path of least deflection has been taken

In this work, we use a recently published two fibre model[2] to derive connectivity estimates which account for partial volume effects separately. This enables us to present two different but related indices: the probability of connection between two points, and the expected proportion of the fibres within the seed voxel that contribute to a connection to the target point.

Methods

The data used in this study was acquired on a Bruker MedSpec S300. The voxel size was 1.5x1.5x2.0mm and data was acquired coronally for 63 isotropically oriented diffusion directions and b=1000s/mm^2. Inference of fibre orientation was initially performed using the Hosey algorithm[2], calculating the probability density function of the orientation of a single fibre and a two fibre population at each voxel. Also calculated were the relative likelihoods of each fit (the Bayes Factors) for each voxel. Tractography was then performed using a Monte Carlo simulation of fibre path from a seed point (assuming a single fibre per voxel), to produce a standard single fibre probabilistic tractography visitation map (p-map). The step length for each segment of the tract was 0.75mm.

The expected proportion of connection allowing for partial volume effects was then estimated as follows. First, a sample of the orientational information for a two fibre fit was generated for each voxel. A tract was then generated. When a tract reached a voxel, containing two fibre populations, the path taken was chosen probabilistically with relative likelihood generated by the product of the cosine of the angle between the path direction on incidence to the voxel and the fibre orientations, and the relative partial volumes of the two fibres. Two fibre populations were identified when the logarithm of the Bayes Factor was greater than 10. This procedure was repeated to give an estimate of the proportion of connection from the seed point to all other voxels. The probability of connection for this data (assuming the model is correct) is one for all voxels visited, and zero elsewhere.

Subsequently, in order to address uncertainty due to other sources of error, this step was repeated for further samples of the orientation parameters. The expected proportion of connection was then derived as the mean of the estimates (we call this a pr-map). A more standard two fibre connection probability map (p-map) was derived from the same data.

In order to compare the behaviour of the algorithms a segmented brain atlas[3] was registered to the same space as the diffusion images. A seed voxel was chosen in the thalamus and the probability of connection and the expected proportion of connection between that point and all points in the paracentral lobule were calculated. The peak value of the indices in this region are presented in Table 1.

Results & Discussion

	Peak value
One Fibre	0.49
Two Fibre probability	0.60
Two Fibre proportion	0.09

Table 1: Peak values of the indices

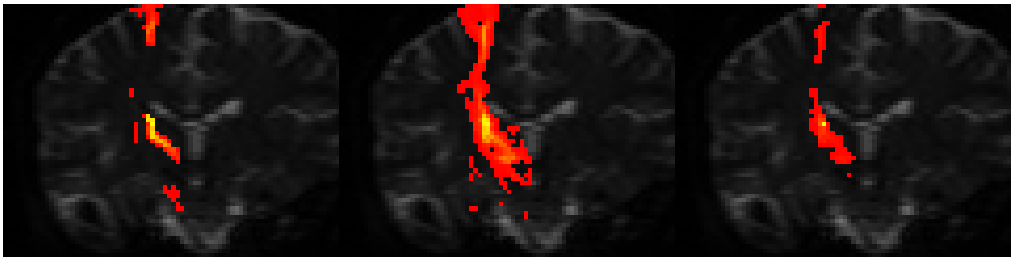

Fig 1: 1-Fibre p- map (p>0.01) Fig 2: 2-Fibre p-map (p>0.01) Fig 3: 2-Fibre pr-map (pr > 0.01)

Figs. 1, 2 & 3 show the tracts, thresholded to exclude rarely visited voxels. It can be seen from Figs. 1 and 2 that the two fibre model gives a higher probability of connection than the single fibre model for a given voxel, and a wider volume of connected voxels. This is to be expected since partial volume errors should be reduced in the two fibre model and it will allow fibre bifurcation and divergence. It is likely, however, that we have reduced the number of false negative errors in favour of false positive errors. The calculation of the proportion of fibres (Fig. 3) from the seed voxel that reach the cortex is low – this is anticipated when we are allowing tracks to effectively "split" from the main track directions. This is reflected in the maxima reported in Table 1.

The two fibre model applied in this work for calculating partial volumes is crude and more sophisticated algorithms for considering intra-voxel partial volume crossings will allow more accurate modelling of the proportion of connection. Similarly, the algorithm for choosing the fibre to follow is arbitary. This could be better informed by prior knowledge of the likelihood of curvature at different brain regions. Tractography algorithms are inherently limited by the resolution at which the original data was acquired; considering the proportion of fibres from the original seed voxel connected to target voxels, as well as the probability of connection, allows a proper consideration of this form of error. It is likely to be most useful when considering fibres which bifurcate or diverge.

1. Parker, 2005, BJR, 77:176-185; 2. Hosey et al, MRM in press; 3. Tzourio-Mazoyer et al, 2002, NeuroImage, 15: 273-289