How Many Streamlines Should I Use?

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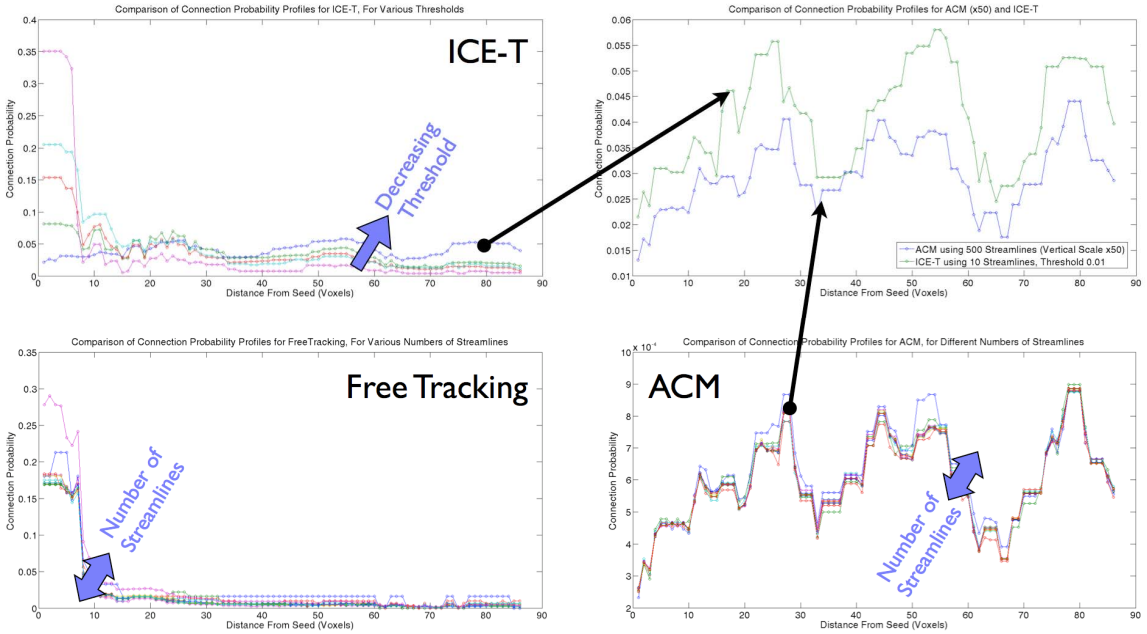
Introduction

In probabilistic streamline tractography, the choice of the number of streamlines to use is the source of much confusion. It is known that in order to sufficiently sample the voxelwise fibre orientation distributions so that a reasonable picture of the network of connections can be delineated, some minimal number of streamlines must be used [1]. But without a handle on the effects of the parameter upon the resulting tracts, the optimisation strategies necessary to determine this minimal number are difficult to implement. Herein we describe an investigation of the influence of the number of streamlines, compare also the parameter's effect within Anatomical Connectivity Map (ACM [2]) generation - a technique for whole bain tractography in which every brain voxel is seeded - and show how, via use of the ICE-T Framework (a recent technique to iterate conventional tractography routines [3]), as few as 10 streamlines per voxel can be sufficient.

Methods

A high quality (SNR=25) post-mortem dataset of the porcine brain (diffusion weighted 2D single spin echo sequence, fullbrain coverage via two interleaved sets of 35 slices, TR = 6500 ms, TE = 67.1 ms, slice thickness 0.5 mm, gap 0.5 mm, matrix: 128 x 128, in-plane resolution: 0.51 x 0.51 mm^2, diffusion sensitization gradient duration 27 ms / time between gradient pulse onsets 33.5 ms, gradient strength 56 mT/m, b value 4009 s/mm^2), acquired for a previous study [4], was employed for testing. The ipsilateral portion of the cortico-nigral tract, from the seed region in the somatosensory area to the substantia nigra, was segmented using a previously reported method [3], verified to be valid via independent in-vivo tracer data (also acquired for the previous study), and its centreline identified. Free tracking was implemented from the seed using the Camino package [5] and the following parameters: multitensor reconstruction with maximum 2 directions, FACT streamline propagation [6], maximal curvature constraint 80 degrees. A selection of different numbers of streamlines were used: [1,3,5,10,20,25,50,100,250,500,5000,64000]. The ACM was also calculated for the whole brain, using the following collection of numbers of streamlines: [1,3,5,10,20,25,50,100,250,500]. Additionally, the ICE-T Framework [3] was employed, using the same tracking parameters as used by the free-tracking routine, and with the number of streamlines fixed at 10. The ICE-T Framework was iterated until stability in the spatial extent of the seed region was attained. The method's internal threshold (a corresponding sensitivity parameter) was fixed at the following levels: [0.01, 0.05, 0.10, 0.15, 0.20]. For each resultant connection probability volume generated by the three methods, the voxels along the tract's midline were replaced by the maximum value found within a radius of 5 voxels in order to ensure no method-specific differences in spatial alignment were introduced. The centreline voxels were then sampled and their profiles plotted.



Results

The free-tracking results highlight the severe problem of the path-length dependency (PLD) effect upon conventional probabilistic streamline tractography results. They demonstrated very little response to an increase in the number of streamlines, and even the largest number attempted (64,000 streamlines per voxel) failed to achieve any increase in the distal connection probability scores of this very prominent tract. In contrast, the ICE-T results, employing only 10 streamlines, showed substantial dependence upon the method's threshold parameter, with the slope from seed to terminal exhibiting rapid changes. The final profile, obtained after 20 iterations at 0.01 threshold, actually produced a positive slope, indicating a probable absence of PLD. The shape of this profile showed great similarity to those of the ACM, which in turn showed very little dependence upon the number of iterations (streamlines) employed.

Conclusion

The connection probabilities of the free-tracking from a seed region showed little or no dependence upon the number of streamlines employed per voxel, and even very high numbers (64,000) of streamlines failed to improve the distal connection probabilities significantly. This is assumed to be a result of the severe influence that PLD has upon the resultant connection probability maps. In contrast, the ICE-T Framework showed marked improvement as its threshold was decreased, using only 10 streamlines per voxel. Whereas the ACM, which can be assumed to be unaffected by PLD (at least to the same extent as free-tracking), shared its shape profile with that of the ICE-T method, it too showed remarkable independence of the number of streamlines parameter. In summary, whereas the ACM is useful for assessing the pattern of connectivity across the brain, generation of a hypothesis-based connection probability map from a specific seed region is far more efficiently and accurately obtained via the ICE-T Framework than by simply employing huge numbers of streamlines in free-tracking.

References

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