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Subpixel Curvature Estimation of the Corpus Callosum via Splines and its Application to Autism

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Introduction

Autism is a neurodevelopmental disorder with abnormal corpus callosum (CC) size [1]. Most previous studies used the area of predefined Witelson partition [5] as a morphometric measure but other shape metrics have not been considered. We present a new computational technique for curvature estimation via piecewise quintic splines and use it in both CC nonlinear dynamic time warping algorithm [4] and detecting the regions of curvature difference.

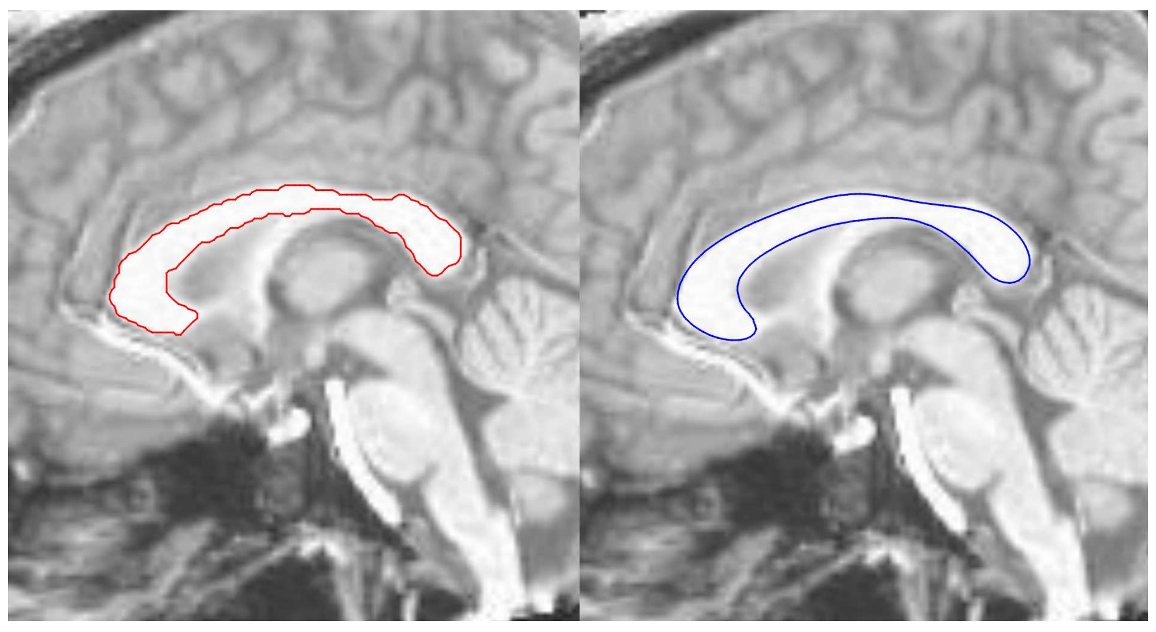

Figure 1: Left: level set segmentation showing partial volume effect. Right: spline smoothing. A similar approach has been taken in [6].

Methods

A group of 2D mid sagittal cross section images of the corpus callosum was taken from males of similar age, 15 autistic, and 12 normal controls. The level set method was used to extract the boundary Ψ of the corpus callosum automatically by solving

$$\frac{\partial \Psi}{\partial t} + F|\nabla \Psi| = 0$$

where F is the given boundary propagation velocity [2]. Then the pixelated CC contour was reconstructed into a rough closed curve in Euclidean space (Figure 1. red). Smoothing of this zigzag contour was necessary to account for the partial volume effect (Figure 1. blue). Two different methods were used to smooth and estimate the curvature function. The first method uses Taubin's smoothing [3], a Gaussian filtering without shrinkage, followed by the least-squares estimation. The second method uses quintic splines to estimate the first and second derivatives to compute the curvature:

$$\min_g \frac{1}{n}\sum_{j=1}^{n}[Y_j - g(t_j)]^2 + \lambda \int [g'''(t)]^2 \, dt.$$

Afterwards a curve from the control group was chosen as a template and all other curves were registered to the template. First an affine registration was used to normalize the global CC size differences. Second the fast nonlinear dynamic-time warping algorithm was used [4]. The algorithm penalized against large deformation and curvature difference, thereby matching the extrema of curvature while maintaining a smooth and stable deformation. So we estimate the deformation d by minimizing

$$\frac{1}{n}\sum_{j=1}^{n}\|X(t_j) - X(d(t_j))\| + \lambda \int \left|\kappa_1(t) - \kappa_2(d(t))\right| \, dt$$

where X is a parameterization of CC and κ_j are the curvature functions. After registering the curves, a local estimation of curvature could be compared across subjects, using Welch's t-test at each point to correct for the somewhat unequal variance in a few areas (Figure 4).

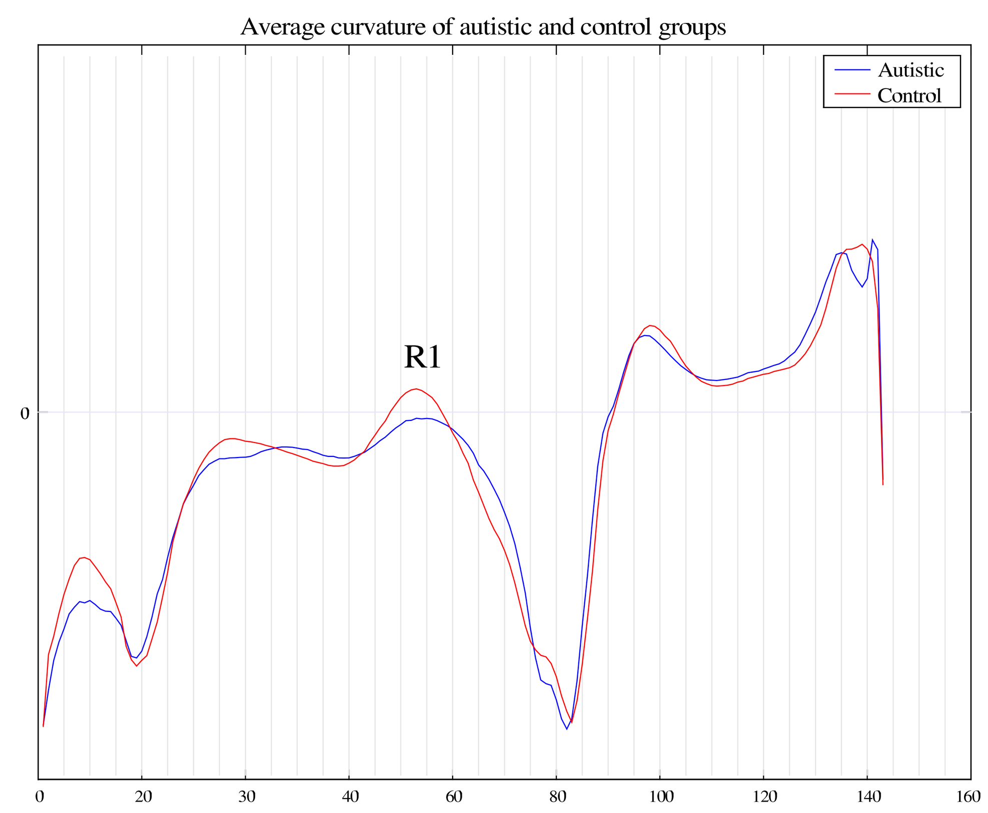

Figure 2: Mean curvatures of autistic (blue) and control (red) groups showing different curvature patterns. R1 is the posterior midbody.

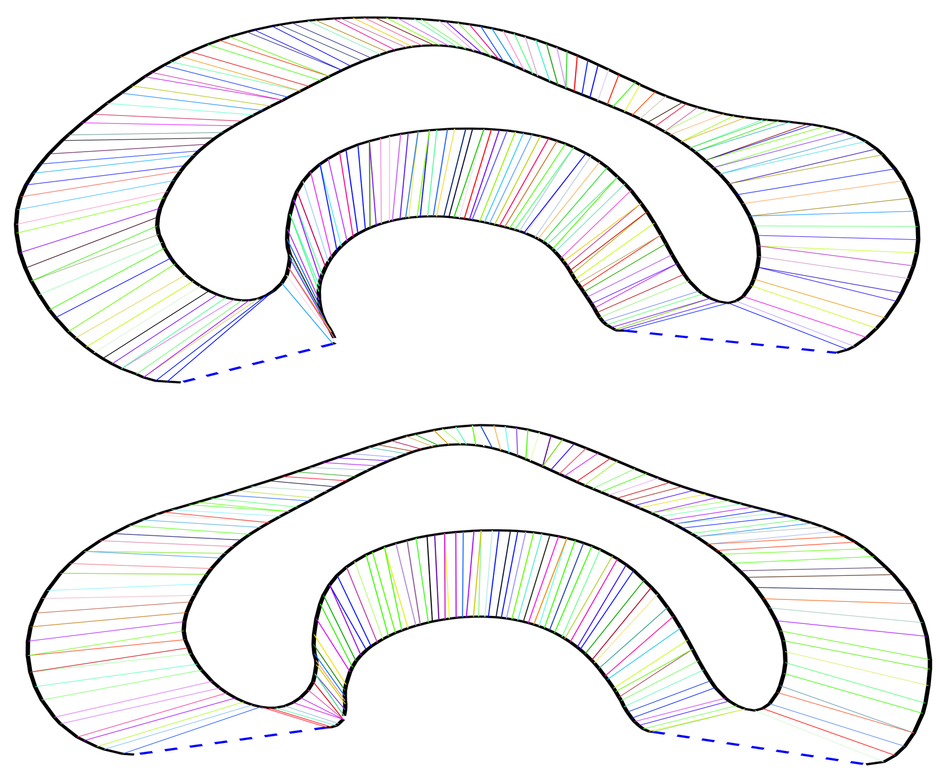

Figure 3: Outer curve: template, inner curve: individual CC boundary. The template has been enlarged to show the pattern of curve registration.

Results

Both methods provided effective estimates of curvature for the entire CC contours. The smoothing splines performed better in terms of ease of fit and more stable results. The results of the comparison of curvatures between the autistic and control subjects are shown in Figure 2 where the sample mean curvature functions are plotted (blue: autistic, red: control). Figure 5 is the uncorrected P-value map where the blue areas indicate more significant curvature difference. Most significant curvature difference is detected at the posterior midbody (R1).

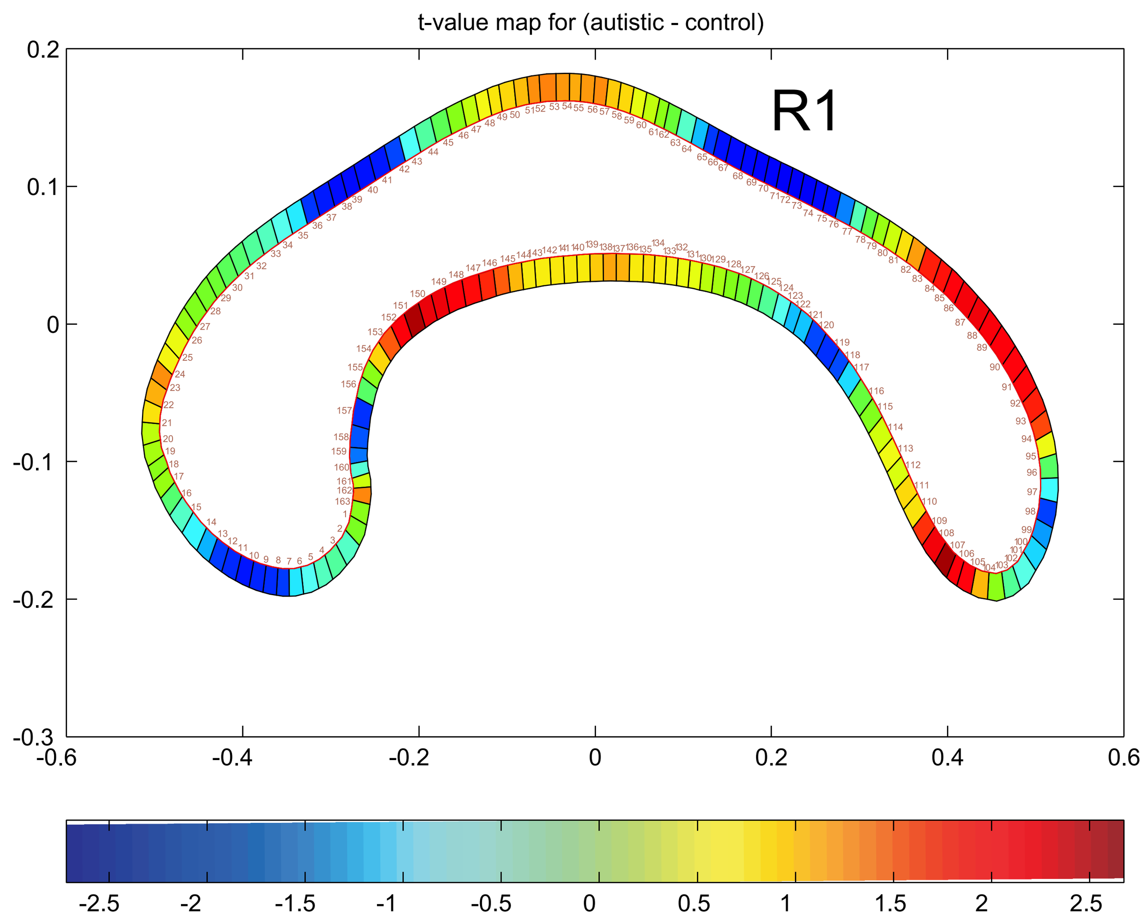

Figure 4: t-statistic map of curvature difference between autistic and control groups.

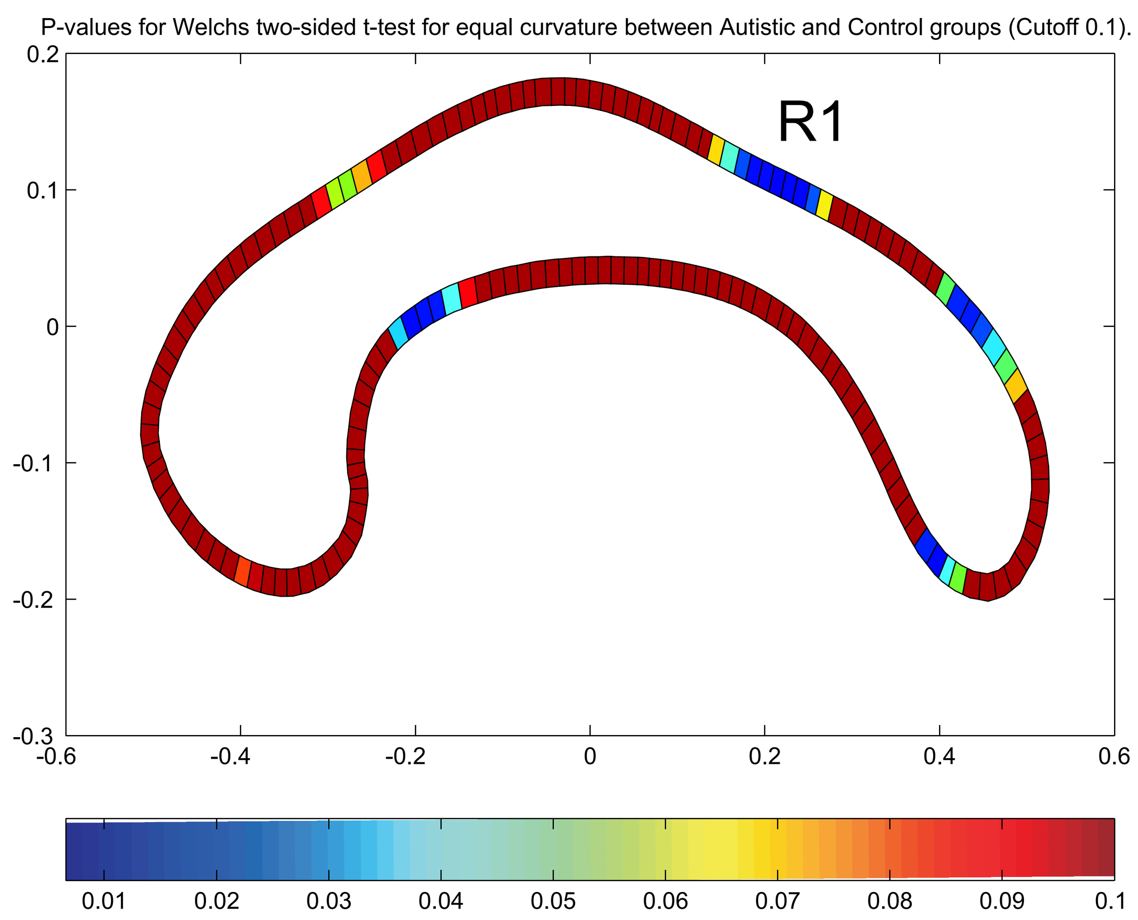

Figure 5: P-value map of curvature difference between two groups.

Acknowledgements

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References

[1] Harden, A.Y. et al. Corpus Callosum Size in Autism. Neurology, **55**:1033-1036, 2000.

[2] Malladi, R. and Sethian, J.A. An o(n log(n)) Algorithm for Shape Modeling. Applied Mathematics **18**:9389–9392, 1996.

[3] Taubin, G. A Signal Processing Approach to Fair Surface Design. Computer Graphics, **29**:351–358, 1995.

[4] Wang, K. and Wang, Y. Alignment of Curves by Dynamic Time Warping. Annals of Statistics, **25**:1251–1276, 1997.

[5] Witelson, S.F. Hand and sex differences in the isthmus and genu of the human corpus callosum. Brain **112**:799–835. 1989.

[6] Carew, J.D., Dalal, R.K., Wahba, G. and Fain, S.B. Estimating arterior wall shear stress. Tech. Report 1088, University of Wisconsin.