Comparing methods to compute and analyse cortical area and volume

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1 Introduction

We compare four different methods for areal analyses: (1) retessellation, (2) redistribution, (3) nearest neighbour interpolation with Jacobian correction, and (4) pycnophylactic. We also evaluate two methods for measuring cortical volume: (1) the multiplication of thickness by area, and (2) an analytic method that uses the coordinates of the vertices of both cortical surfaces, leaving no tissue unrepresented.

2 Method

The retessellation method was described by [Saad 2004]; the pycnophylactic method by [Winkler 2012]; the redistributive method consists of reassigning areal quantities on proportions determined by barycentric coordinates. The nearest neighbour interpolation followed by Jacobian correction is the default method in the FreeSurfer, executed by the command `mris_preproc`. The four methods were computed using three different resolutions (ic3, ic5 and ic7), without and with smoothing (FWHM 10 mm).

For volumes, the proposed analytical method consists of using each face of the white surface and its corresponding face in the pial surface to define an oblique truncated triangular pyramid, which is subdivided into three tetrahedra, the volumes of which are computed from their vertex coordinates.

3 Results

At the highest resolution (ic7), all areal methods preserved generally well the global amount of surface area. However, in various cases the differences were substantial. At lower resolutions, massive amounts of area are lost with the retessellation method (about 40% for ic3, 9% for ic5, 1% for ic7). At the subject level, the spatial correlation between the nearest neighbour method and the pycnophylactic method is about 0.60 only, although near unity when the subjects are averaged.

Smoothing leads to dramatic improvement, causing nearest neighbour to be nearly indistinguishable from the pycnophylactic method. The redistributive method performed in a similar manner, although with a correlation somewhat higher without smoothing, about 0.75. In terms of speed, although the various implementations differ, the pycnophylactic method is far slower than the others.

Differences between the two volume methods at the local scale could be as high as 20%, and these differences could not be alleviated by smoothing or changes in resolution.

4 Conclusion

Both area and volume methods differ quantitatively. If high resolution meshes and smoothing are used, `mris_preproc` likely offers the best trade-off in terms of speed and preservation of areal quantities, yielding nearly identical results as the pycnophylactic, which is far more demanding computationally. The two volume methods differ substantially, warranting replacement of the classical for the one proposed.

5 References

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Figure 1: (*a*) If the volume is computed using simple multiplication of thickness by area, considerable amount of tissue is left unmeasured in the gyri, or measured more than once in sulci. The problem is minimised, but not solved, with the use of the mid-surface. (*b*) Instead, the vertex coordinates can be used to compute analytically the volumes of tissue between matching faces of white and pial surfaces, leaving no tissue under- or over-represented.

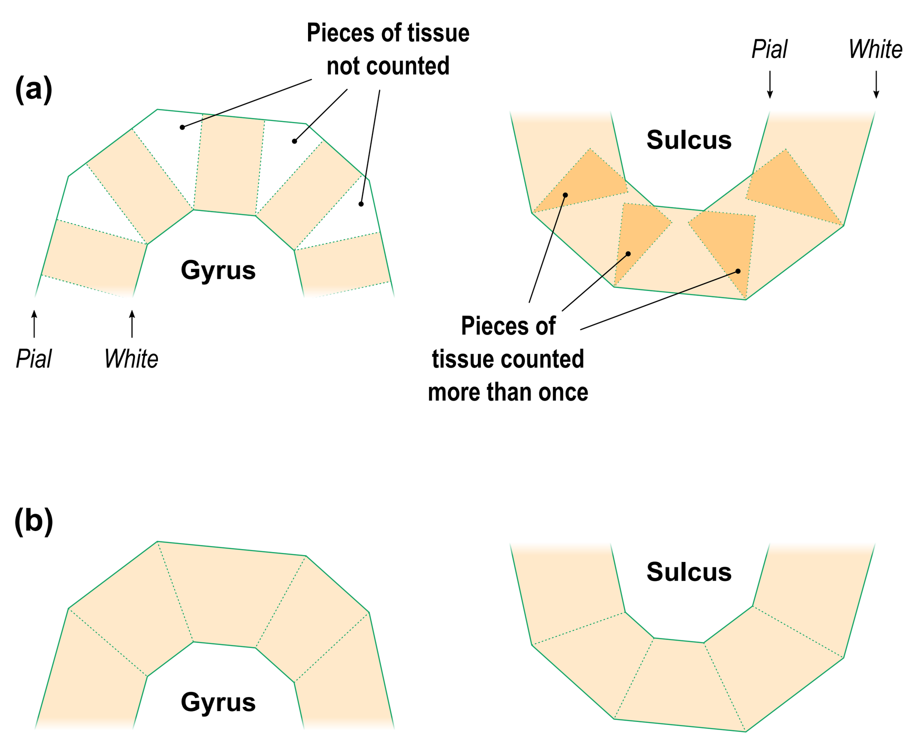


Figure 2: (*a*) In the surface representation, the cortex is limited internally by the white and externally by the pial surface. (*b*) and (*c*) These two surfaces have matching vertices that can be used to delineate an oblique truncated triangular pyramid. (*d*) The six vertices of this pyramid can be used to define three tetrahedra, the volumes of which are computed analytically

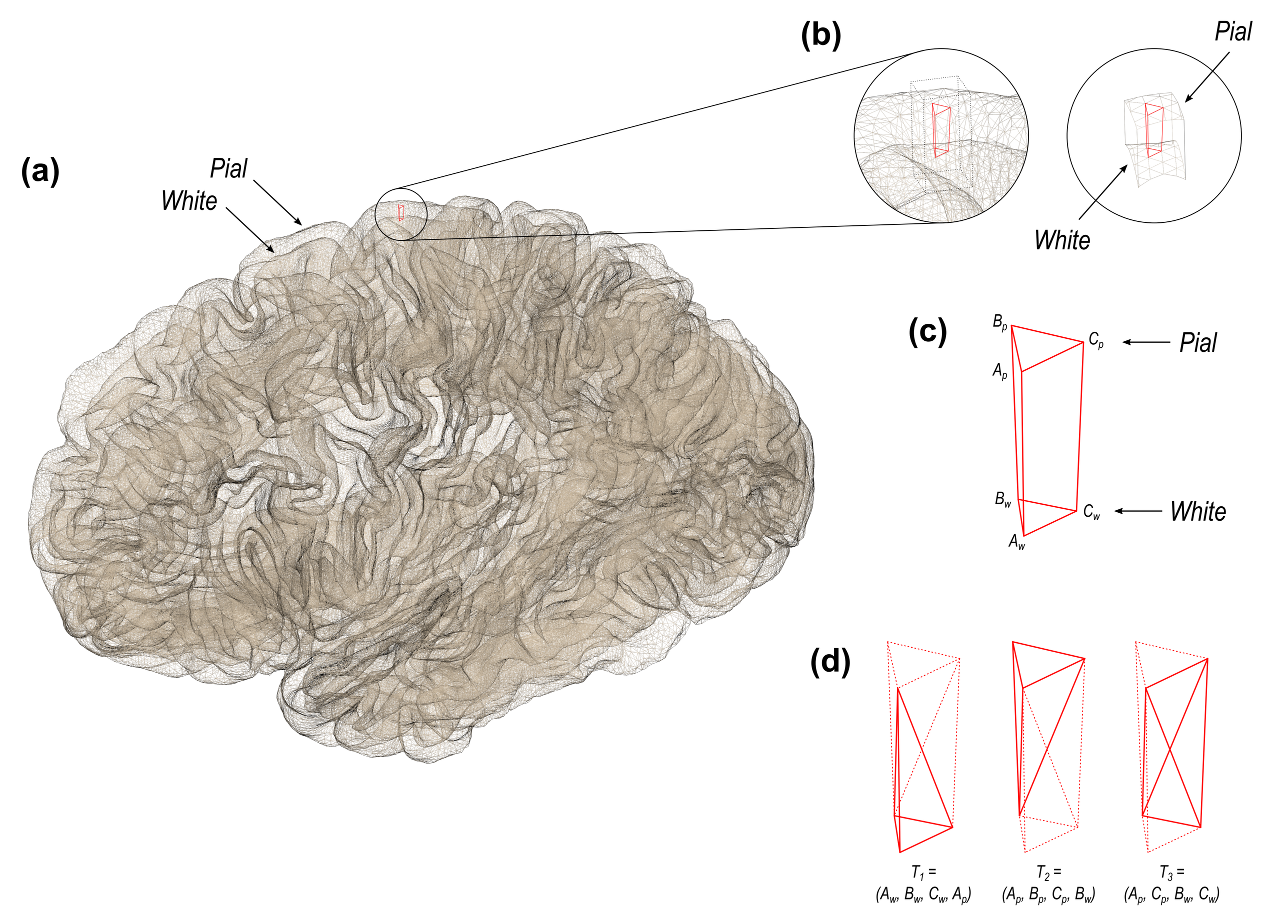


Figure 3: Average difference between the four interpolation methods, at different resolutions and with or without smooting with a FWHM = 10 mm. Losses in area are pronounced for the retessellation method at lower resolutions. Agreement between the methods improves at higher resolutions, with nearest neighbour, pycnophylactic, and redistributive being virtually indistinguishable in the ic7 after smoothing.

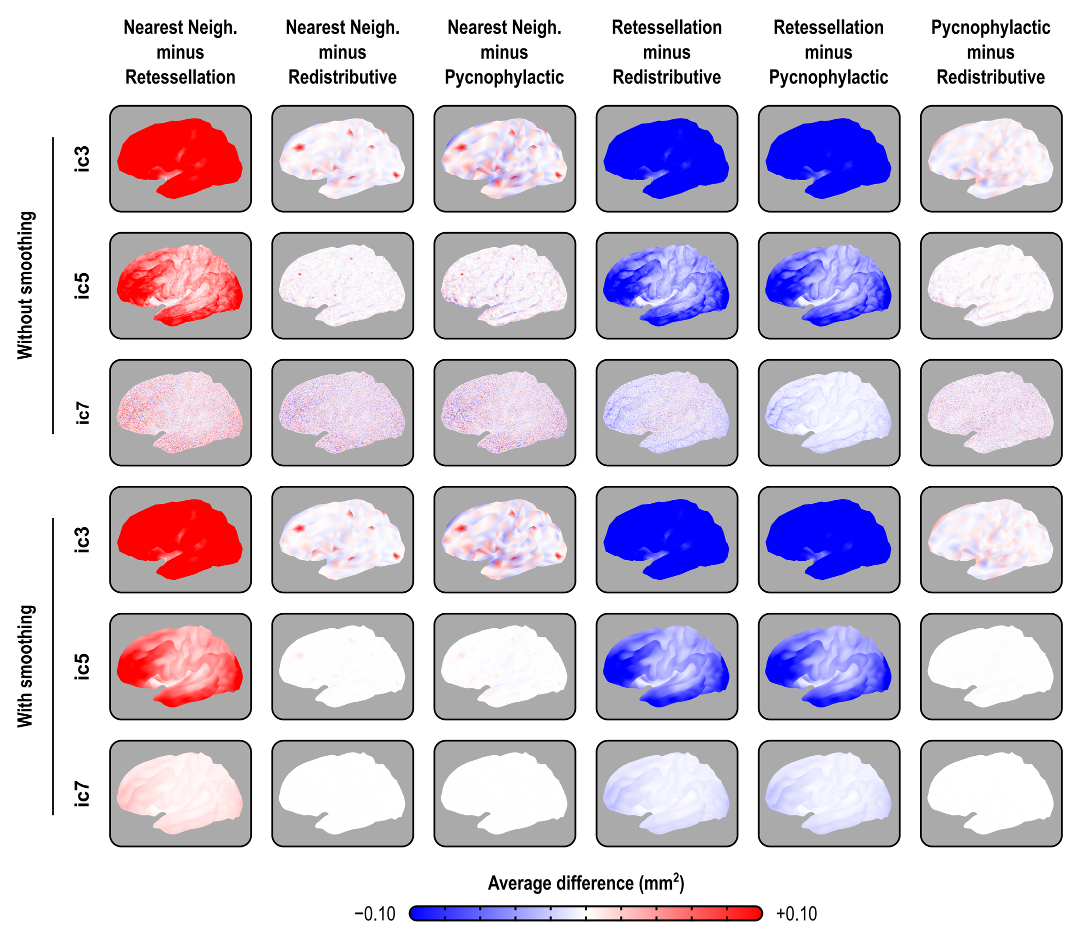
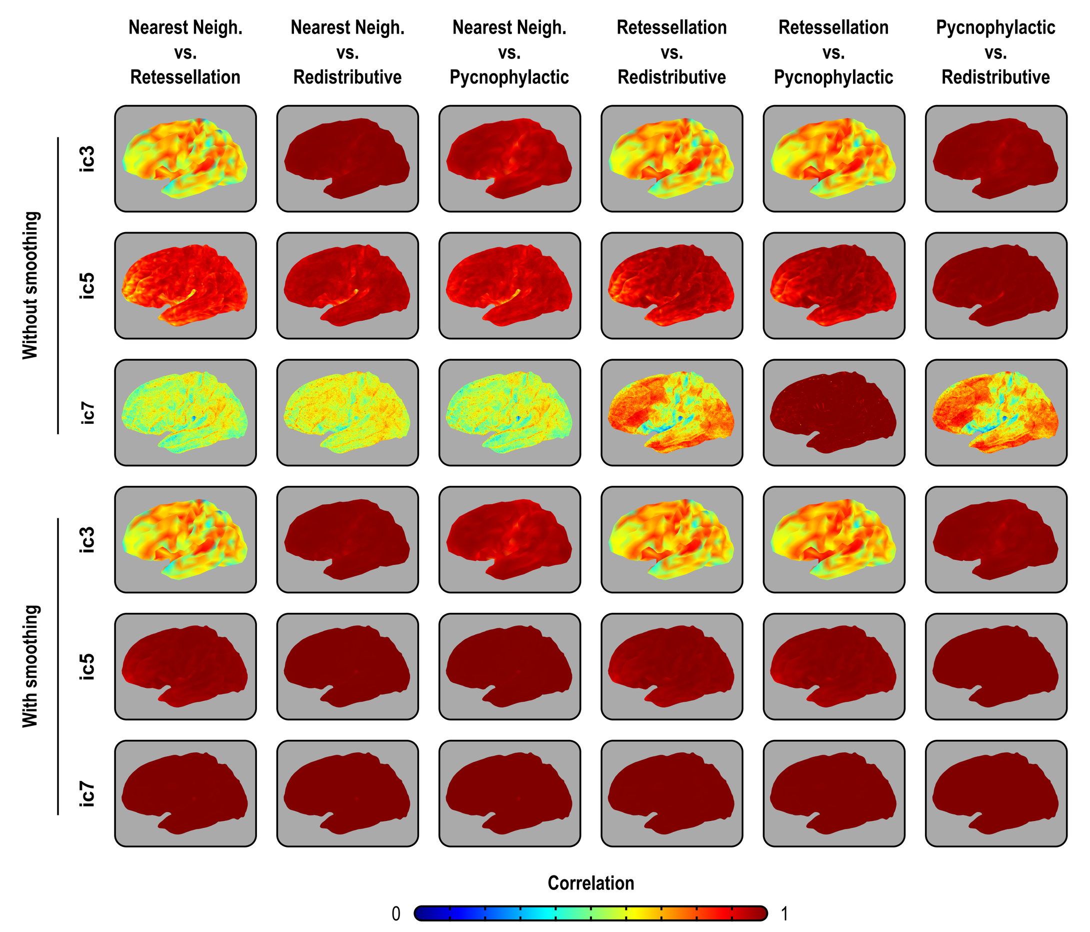


Figure 4: Correlations between the four interpolation methods (across subjects), at different resolutions and with or without smoothing with a FWHM = 10 mm. Correlation of retessellation with the other methods is generally poor at lower resolutions, but improve as resolution increase and if smoothing is applied. With smoothing and at moderate or high grid resolution, all methods have very high correlation.



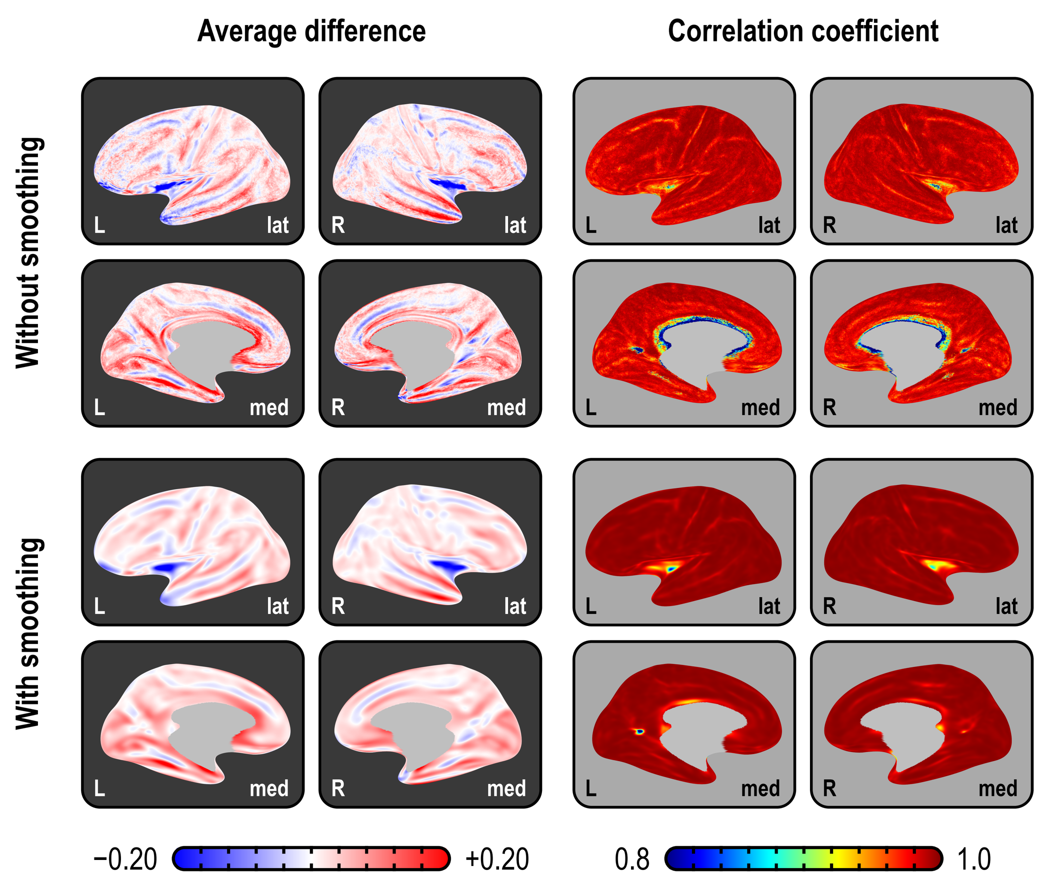


Figure 5: Maps comparing the average difference (in mm^3) between the two methods of assessing volume and their correlation (across subjects). As anticipated from Figure 1, differences are larger in the crowns of gyri and in the depths of sulci, with gains/losses in volume following opposite trends in these locations. Although the correlations still tend to be generally high, and increase with smoothing, they are still relatively low in some regions of higher variability, such as at the anterior end of the cuneus, and in the insular cortex.

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