UNC Spatiotemporal Neonatal Cortical Surface Atlases

Version 1.0

The University of North Carolina (UNC)'s spatiotemporal neonatal cortical surface atlases contain **a collection of atlases at each week from 39 to 44 postmenstrual weeks**, thus well characterizing the dynamic brain development during the first postnatal weeks.

1. Neonatal Cortical Surface Atlas Description

The neonatal cortical surface atlases constructed from a large representative population are highly needed in neonatal neuroimaging studies [1]. However, existing neonatal cortical surface atlases have two limitations:

(1) They are typically constructed from small datasets, e.g., tens of subjects, which are inherently biased and thus are not representative to the neonatal population;
(2) The cortical folding patterns are not well captured and represented on these existing neonatal cortical surface atlases.

To address these limitations, we construct neonatal cortical surface atlases based on a large-scale dataset with **764** healthy subjects. To better characterize the dynamic cortical development during the first postnatal weeks, instead of constructing just a single atlas, we construct a set of **spatiotemporal atlases at each week from 39 to 44 postmenstrual weeks**. To preserve the sharp cortical folding pattern on the atlases, rather than simply averaging over the co-registered cortical surfaces and their properties, which generally leads to over-smoothed cortical folding patterns, we adopt a **spherical patch-based sparse representation** method by using an augmented dictionary to overcome the noise and potential registration errors. By doing this, our atlases preserve sharp cortical folding patterns, which leads to better image registration and analysis accuracy when aligning new subjects to atlases.

2. Where to download

The package can be freely downloaded from:

https://www.nitrc.org/projects/infantsurfatlas/

It is freely available to the public for the purpose of academic research.

3. What it includes

Our spatiotemporal neonatal cortical surface atlases are distributed in three popular file formats: a) **VTK (*.vtk) format**, which can be visualized and processed by any VTK supported toolkit, such as ParaView; b) **FreeSurfer format**, which can be used and incorporated in the FreeSurfer package; c) **HCP (*.gii) format**, which is in accordance with the workbench toolkit developed under the HCP project.

For each of the six postmenstrual weeks (from 39 to 44 weeks), we provide:

a) The spherical representation and white matter surface (inner surface) of each hemisphere of the population cortical structures (with 163,842 vertices). The left hemisphere (lh) and right hemisphere (rh) are represented in two separate files. The white matter surface is isomorphic to the spherical representation (spherical surface), with a vertex-to-vertex cortical correspondence.

b) The average convexity and mean curvature of each white matter surface, as well as the mean curvature of each inflated white matter surface. These metrics are generally useful for cortical surface registration.

c) The FreeSurfer Desikan parcellation [2] (with 35 ROIs in each hemisphere) and the HCP MMP parcellation [3] (with 180 ROIs in each hemisphere).

Fig. 1 shows the constructed spatiotemporal neonatal cortical surface atlases for the left hemisphere at each postmenstrual week. Columns (a) – (b) illustrate the cortical properties on the standard sphere; Columns (c) – (d) illustrate the corresponding cortical properties on the age-specific population-averaged inner cortical surface; Columns (e) and (f) illustrate the FreeSurfer Desikan parcellation and HCP MMP parcellation map at each time point.

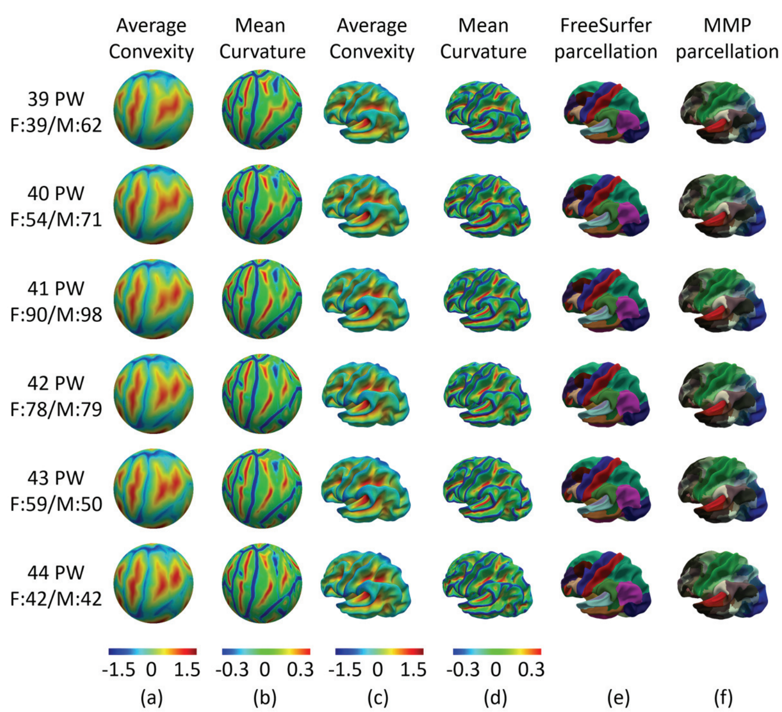

Fig. 1. UNC spatiotemporal neonatal cortical surface atlases and parcellations from 39 to 44 postmenstrual weeks (PW). The subject number with gender information at each time point (with M indicating male, and F indicating female) is provided on the left.

4. File illustration

There are 3 folders, each with one format of the neonatal spatiotemporal cortical surface atlases.

a) For VTK format, we appended all morphological features (properties) and the parcellation labels into the surface files. Totally, for each time point, there are 4 files. The typical file name is: [***Month***]/[***Hemi***].[***Surface***].vtk. The illustration of the name field strings is listed in **Table 1**.

b) For FreeSurfer format, the surfaces, morphological features and parcellations are provided in separate files. For each time point, there are 16 files. We have followed the FreeSurfer naming strategy to name our surface atlases. The typical surface file name is: [***Month***]/[***Hemi***].[***Surface***]; the typical morphological feature filename is: [***Month***]/[***Hemi***].[***Feature***]; and the typical parcellation filename is: [***Month***]/[***Hemi***].*Annot*-[***Parcellation***]. All related name field strings are also listed in **Table 1**.

c) For HCP format, the surfaces, morphological features and parcellations are also provided in separate files. For each time point, there are 14 files. We have followed the general HCP naming strategy to name our atlases. The typical surface file name is: [***Month***]/[***Hemi***].[***Surface***].164k.surf.gii; the typical morphological feature filename is: [***Month***]/[***Hemi***].[***Feature***].164k.shape.gii; while the typical parcellation filename is: [***Month***]/[***Hemi***].[***Parcellation***].164k.label.gii.

Table 1. The name field value for each data format.

Name field	**VTK**	**FreeSurfer**	**HCP**
Postmenstrual Week	{39, 40 ,41, 42, 43, 44}		
Hemi	{lh,rh}	{lh,rh}	{L,R}
Surface	{InnerSurf, SphereSurf}	{white, sphere}	{white, sphere}
Feature	Appended into surface {curvature, InflatedCurv, Convexity}	{curv, inflated.H, sulc}	{Curvature, InflatedCurvature, AverageConvexity}
Parcellation	Appended into surface {par_FS, par_MMP}	{FreeSurfer, MMP}	{ParcellationFreeSurfer, ParcellationMMP}

5. How it was constructed

T2-weighted MR images from 764 healthy neonates from 39 to 44 postmenstrual weeks were acquired. Subject number and gender at each age are reported in **Fig. 1**, with M/F indicating male/female, respectively. All images are processed by UNC Infant Cortical Surface Pipeline [4, 5]. The topologically-correct and geometrically-accurate cortical surfaces are reconstructed [6] and then smoothed and inflated to a sphere [7] to facilitate the registration of individual cortical surfaces.

Our method mainly includes 3 steps:

(1) We first establish unbiased cortical correspondences across all subjects using group-wise spherical surface registration [8] and then resample the registered spherical surfaces using the same mesh tessellation.
(2) Then, for each local spherical patch in the atlas space, we build a dictionary that includes not only the corresponding patches from age-matched and co-registered cortical surfaces, but also the spatially-neighboring patches [9, 10] to account for possible registration errors.
(3) Finally, using the constructed dictionaries, the problem of estimating cortical folding properties (e.g., average convexity and mean curvature) on the atlas patch becomes finding the best representation of the population folding property using the respective dictionary. Notably, each cortical folding property can be regarded as a specific view of the cerebral cortex and all properties should be consistently represented on the atlas.

Therefore, instead of representing them independently [9], we jointly represent them using a **multi-task sparse representation** with group-wise sparsity constraint [10, 11], where each task corresponds to a specific property representation. Using the above method, we not only preserve sharp cortical folding patterns, but also maintain consistency across different folding properties on the atlases.

To equip our neonatal cortical surface atlases with parcellation maps, the population-specific spherical surface atlases were aligned onto our previously established UNC 4D Infant Cortical Surface Atlas [4], which has been linked with the FreeSurfer adult atlas. Then, the FreeSurfer Desikan parcellation [2] with 35 regions and the HCP MMP parcellation [3] with 180 regions in each hemisphere was propagated to our spatiotemporal neonatal cortical surface atlases. Note. **Our released neonatal and infant cortical surface atlases are all in the same space with the FreeSurfer adult atlas**.

6. How to use

Our spatiotemporal neonatal cortical surface atlases can be used to register an individual's cortical surface into a common space and also propagate the parcellations onto the individual's cortical surface. Here, we provide registration examples when using FreeSurfer[1] [12] and Spherical Demons[2] [8]. After successful installation and configuration, the pairwise alignment could be done through the following command lines.

[1] https://surfer.nmr.mgh.harvard.edu
[2] https://sites.google.com/site/yeoyeo02/software/sphericaldemonsrelease

For FreeSurfer, one can use the following command:

```
mris_register -1 individual_subject/lh.sphere neonate_altas/lh.sphere individual_subject /lh.sphere.FS.reg
```

For Spherical Demons, one can use the Matlab command:

```
mris_SD_pairwise_register(individual_subject/lh.sphere, neonate_altas/lh.sphere, individual_subject /lh.sphere.SD.reg)
```

When using our spatiotemporal neonatal cortical surface atlases, please cite our following papers:

Li, G., Wang, L., Shi, F., Gilmore, J.H., Lin, W., Shen, D., 2015. ***Construction of 4D high-definition cortical surface atlases of infants: Methods and applications***. Medical image analysis 25, 22-36.

Wu, Z., Li, G., Meng, Y., Wang, L., Lin, W., Shen, D., 2017. ***4D infant cortical surface atlas construction using spherical patch-based sparse representation***. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI), 57-65.

Wu, Z., Li, G., Wang, L., Lin, W., Gilmore, J.H., Shen, D., 2018. ***Construction of spatiotemporal neonatal cortical surface atlases using a large-scale Dataset***. IEEE International Symposium on Biomedical Imaging (ISBI), 1056-1059.

7. Contact

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8. References

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