Use of Cerebellar Landmarks To Define a Coordinate System and an Isolation Strategy

Kelly Rehm[1,3], David Rottenberg[2,3], Kirt Schaper[3], Josh Stern[2,3], Monica Hurdal[4], De Witt Sumners[4]

[1] Department of Radiology, University of Minnesota, Minneapolis, U.S.A. [2] Department of Neurology, University of Minnesota, Minneapolis, U.S.A.
[3] PET Imaging Center, Minneapolis VA Medical Center, U.S.A. [4] Department of Mathematics, Florida State University, Tallahassee, U.S.A.

Introduction

A coordinate system encompassing the cerebellum is necessary for comparing structure and function across subjects. The widely-used Talairach system is often extended to the cerebellum, but this can result in poor structural registration.

We propose a cerebellar coordinate system that is based on readily-identifiable landmarks in the brainstem and cerebellum, shares a reference point - the posterior commissure (PC) - with the Talairach coordinate system, and is compatible with current anatomical atlases (1).

We present a strategy for isolating the cerebellum from the brainstem using this coordinate system and landmark set. Isolation is a prerequisite for 3D and 2D surface mapping of the cerebellum (2).

Methods: Cerebellar coordinate system

We transform a structural MRI volume from its acquisition space into a coordinate system based on cerebellar, rather than cerebral landmarks. The system is based on three anatomical landmarks: the posterior commisure (PC), obex, and the apex of the fourth ventricle (V4) (see Fig. 1).

The original volume undergoes a rigid-body transformation to satisfy the following conditions:
a) the cerebellar midplane forms the central plane of the volume,
b) the posterior commissure is at the midpoint of the volume,
c) the line joining the posterior commissure and the obex is vertical.

The resliced volume (Fig 2.) facilitates examination of cerebellar asymmetry and assists in defining a reproducible approach to isolating the cerebellum from the cerebrum and brainstem.

Methods: Landmark localization

We selected of a set of cerebellar landmarks to use for examining the suitability of the proposed cerebellar coordinate system. Twenty-three MRI volumes were transformed to each of three coordinate systems using the following methods: (**Tal**) Talairach transform (by specifying anterior commissure (AC) and PC points), (**CB**) the cerebellar system described above, and (**CBS**) the cerebellar system further scaled in one dimension to standardize the distance between the PC and the obex.

The selected landmarks (see Table 1) included the bases of major cerebellar fissures as identified by Schmahmann, Doyon, et. al (3). Landmark locations were identified in **CB** space and transformed to **Tal** and **CBS** spaces. Landmark localization was evaluated by examining the spread of landmark locations about the centroid of the group location.

Figure 1. Transformation from cerebral to cerebellar midplane. *Left:* The PC, V4 apex and obex are marked in the native-space volume (although all three points are plotted on the same sagittal slice, in fact the apex of the ventricle was located in the adjacent slice). *Right:* Cerebellar midplane in transformed volume.

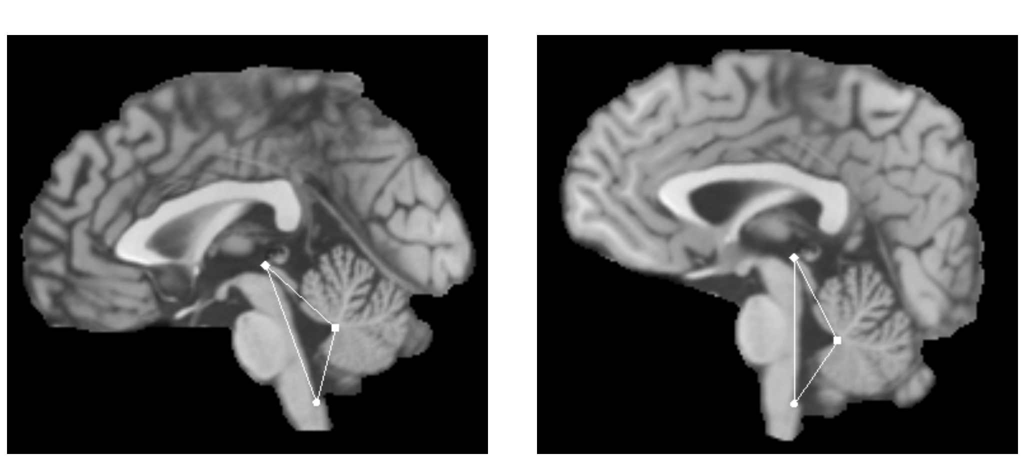
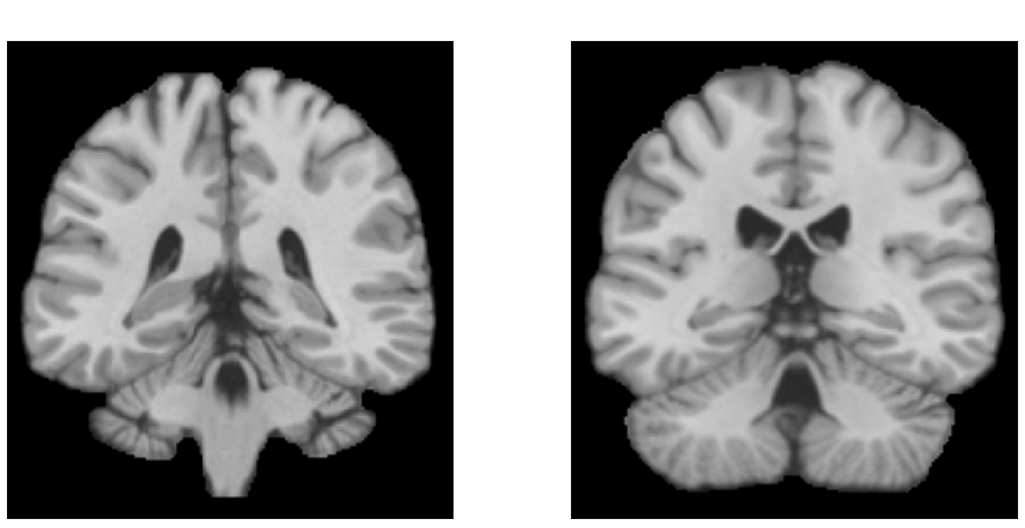


Figure 2. Coronal slice through the tip of the lingula: *Left:* original volume, *Right:* resliced volume.

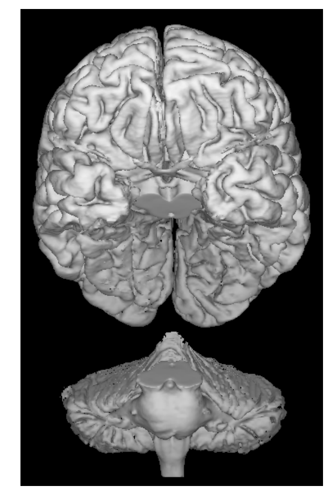


Methods: Isolating the cerebellum

We designed a strategy to isolate the cerebellum from a brain volume (in CB space) that consists only of cerebrum, cerebellum and brainstem prepared by another method (4).

First, the cerebrum is removed by severing the brainstem between the superior and inferior collicula and defining the boundary of the occipital lobes using a 3D editing tool.

Figure 3. Severed cerebrum.

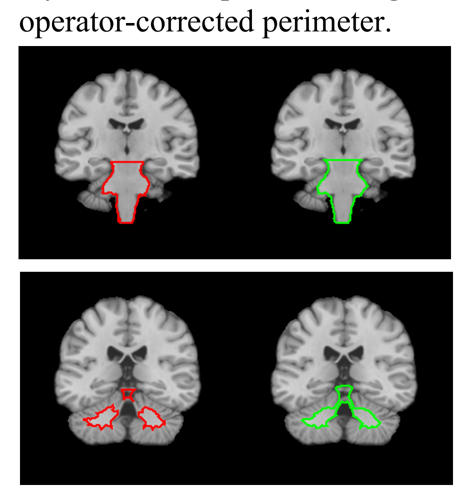


Methods: Isolating the cerebellum

We identify brainstem voxels as a) all of the brainstem anterior to the first coronal slice containing cerebellar grey matter and b) white matter and peduncles up to the slice anterior to the tip of the lingula.

To identify the latter class of voxels we use an operator-supervised iterative method that uses region-growing and local statistics to define the brainstem boundary on each coronal slice.

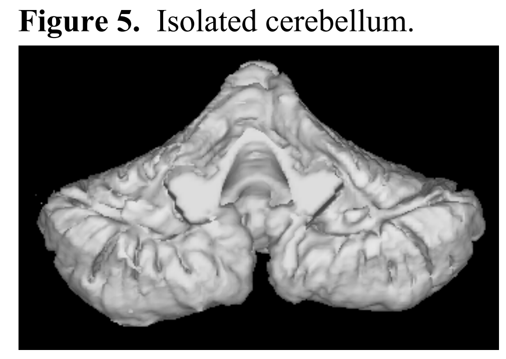
Figure 4. Brainstem voxels. *Left:* automatic perimeter, *Right:* operator-corrected perimeter.



Methods: Isolating the cerebellum

The brainstem peduncles are severed in a consistent manner across subjects by constraining brainstem removal to begin at its anterior surface and to end in the coronal plane adjacent to the tip of the lingula. For each successive coronal slice, the brainstem is "milled-off" along a line-of-sight from the anterior surface. That is, intervening cerebellar grey matter will protect white matter that would otherwise be valid to cut. This strategy results in angled cuts of the cerebellar peduncles and a flat cut surface on the last plane.

Figure 5. Isolated cerebellum.



Results

We identified anatomical landmarks in T1-weighted MRI volumes acquired from a group of twelve young normal subjects (voxel size: 0.86 x 0.86 x 1.0 mm), and eleven subjects with dominant hereditary ataxia (voxel size: 0.86 x 0.86 x 2.0 mm). A single operator located each landmark, with an estimated maximum error of 1.6mm for normal subjects and 2.3mm for ataxic subjects.

Standard distances and landmark localizations are reported in Tables 1-3 for the normal, ataxic and pooled subjects. Note that while the AC and PC points are designated as *fixed* in the **Tal** system and the obex is designated as *fixed* in the **CBS** system, in fact there was some variance introduced by transformation between coordinate systems.
The angle between the cerebellar and cerebral midplanes was also calculated and is reported by its yaw and roll components.

Discussion

The mean ratio of the AC-PC and obex-PC distances in the unscaled CB volumes was 0.51 (s.d. 0.03), indicating that it is reasonable to standardize scaling using the obex-PC distance. When this scaling is applied (transform **CBS**) the localization of all cerebellar landmarks improves relative to the Talairach volumes.

The cerebral and cerebellar midplanes differed for every subject and included both a yaw and a roll component in 87% of the cases. Merely aligning the cerebellar midplanes of the subjects (transform **CB**) improved the localization of landmarks for ataxic subjects.
Of note is that the *minimum* native-space AC-PC distance for normals was 25.9mm -- 2.9mm larger than the Talairach distance -- implying that **TAL** transform localization may compare favorably to **CB** localization for normal subjects merely by virtue of compressing the cerebellum.

Table 1. Landmark localization in twelve **normal** subjects.
(mean [s.d.] reported in mm)

Landmark	TAL	CB	CBS
AC-PC Distance	23.0 [*fixed*]	27.3 [1.1]	27.3 [1.0]
Obex-PC distance	56.2 [2.1]	53.9 [3.0]	54.0 [*fixed*]
AC localization	*fixed*	2.0 [0.4]	2.0 [0.5]
Obex localization	3.8 [1.7]	2.3 [1.9]	*fixed*
V4 apex localization	3.2 [1.7]	3.4 [1.6]	2.7 [1.7]
Lingula localization	2.3 [1.0]	2.3 [0.7]	2.0 [0.6]
Primary fissure	3.1 [1.6]	3.5 [1.7]	2.6 [1.7]
Horizontal fissure	4.2 [1.9]	5.0 [1.9]	4.1 [2.0]
Preculminate fissure	2.7 [1.7]	3.0 [1.3]	2.6 [1.5]
Prepyramidal fissure	3.8 [1.9]	4.4 [1.9]	3.5 [2.0]
Secondary fissure	3.8 [2.0]	3.9 [1.9]	3.1 [2.0]

Yaw angle: 0.6 [s.d. 4.2] Roll angle: 2.4 [s.d. 2.8]

Table 2. Landmark locations in eleven **ataxic** subjects with atrophy.
(mean [s.d.] reported in mm)

Landmark	TAL	CB	CBS
AC-PC Distance	23.0 [*fixed*]	26.9 [1.1]	27.0 [1.0]
Obex-PC distance	52.6 [4.2]	52.9 [3.0]	54.0 [*fixed*]
AC localization	*fixed*	2.2 [0.8]	2.0 [0.8]
Obex localization	6.0 [2.0]	2.1 [2.1]	*fixed*
V4 apex localization	3.8 [1.7]	2.0 [0.8]	1.8 [0.9]
Lingula localization	2.9 [1.1]	1.8 [0.8]	1.7 [0.8]
Primary fissure	3.1 [1.4]	2.5 [0.9]	2.5 [1.2]
Horizontal fissure	4.4 [2.5]	4.1 [1.3]	4.4 [1.6]
Preculminate fissure	3.0 [1.7]	1.6 [0.7]	1.6 [0.7]
Prepyramidal fissure	3.8 [1.5]	2.1 [1.1]	2.4 [1.5]
Secondary fissure	4.0 [1.1]	2.1 [0.9]	2.0 [0.9]

Yaw angle: 0.2 [s.d. 1.9] Roll angle:2.3 [s.d.3.0]

Table 3. Landmark locations in **all** subjects.
(mean [s.d.] reported in mm)

Landmark	TAL	CB	CBS
AC-PC Distance	23.0 [*fixed*]	27.1 [1.1]	27.1 [1.0]
Obex-PC distance	54.4 [3.7]	53.4 [3.0]	54.0 [*fixed*]
AC localization	*fixed*	2.2 [0.7]	2.1 [0.7]
Obex localization	5.2 [2.6]	2.3 [1.9]	*fixed*
V4 apex localization	3.9 [2.1]	2.9 [1.5]	2.4 [1.5]
Lingula localization	2.8 [1.2]	2.1 [0.9]	2.0 [0.9]
Primary fissure	3.5 [1.5]	3.0 [1.6]	2.6 [1.6]
Horizontal fissure	4.4 [2.1]	4.7 [1.8]	4.5 [1.9]
Preculminate fissure	3.1 [1.9]	2.4 [1.3]	2.1 [1.3]
Prepyramidal fissure	4.0 [1.8]	3.3 [2.0]	3.0 [1.9]
Secondary fissure	4.1 [1.9]	3.1 [1.8]	2.5 [1.7]

Yaw angle: 0.4 [s.d. 2.6] Roll angle: 2.4 [s.d. 2.8]

Conclusions

Like the anterior and posterior commissures, the obex is a primitive structure that can support a stable coordinate system. The mismatch of cerebral and cerebellar midplanes, in addition to the variance in obex-PC distance remaining after transformation to extended Talairach coordinates reinforces our belief that cerebella require a distinct coordinate system.

The preliminary 1D rescaling strategy that was investigated had the desired effect of improving the localization of cerebellar landmarks for both normal and ataxic subjects. Though the PC and obex are removed by the cerebellar isolation strategy, the remaining landmarks are retained and can be **visualized in both volume and surface representations** of cerebellar structure and function.

References

1 Duvernoy H.M., The human brain stem and cerebellum. Springer-Verlag, Wein, 1995.
2. Hurdal M., Sumners D.L., Rehm K., Schaper K., Bowers P.L., Stephenson K., Rottenberg D.A. *NeuroImage*. 9(6)S194, 1999.
3. Schmahmann J.D., Doyon J., McDonald D., Holmes C., Lavoie K., Hurwitz A.M., Kabani N., Toga A., Evans A., Petrides M. *Neuroimage*. 10, 233-260, 1999.
4. Rehm K., Shattuck D., Leahy R., Schaper K., Rottenberg D.A. *NeuroImage*. 9(6)S86, 1999.

Acknowledgments

This work is support in part by NIH grants MH57180 and NS33718.