Paracingulate Sulcus Measurement Protocol
V2.
Tailored for BrainVISA

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This protocol is an updated version of 'Paracingulate Sulcus Measurement Protocol' (Garrison, 2017 https://doi.org/10.17863/CAM.9986) and is now tailored for use in BrainVISA (https://brainvisa.info). The current protocol aims to identify and label the paracingulate sulcus using a 3D reconstruction of the grey-white matter interface of the brain and a visualisation of sulci as produced by the BrainVISA software. These reconstructions are dependent on the quality of the input T1 image and quality control of the raw T1 images (e.g., checking for movement artifacts, blur, or low grey/white contrast) is advisable prior to application of the protocol to the BrainVISA reconstructions.

Vertical Anterior Commissure (VAC) and Vertical Posterior Commissure (VPC) lines:

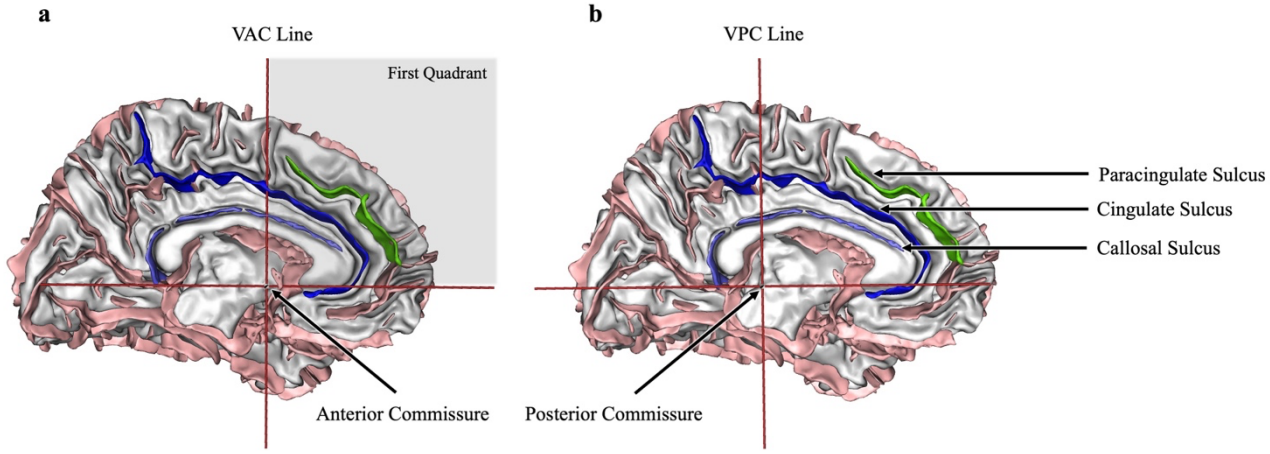

Fig. 1. Representation of the VAC and VPC lines. *The cross-mesh cursor is positioned on the anterior commissure (a) and posterior commissure (b), in a left hemisphere in which the callosal, cingulate and paracingulate sulci have been labelled.*

In the 'Talairach AC-PC referential'

- When the cross hairs are placed on the anterior commissure, the vertical line is called the VAC line, and the upper anterior quadrant is hereby called the first quadrant (*cf.* Fig.1.a).
- When the cross hairs are placed on the posterior commissure, the vertical line is called the VPC line (*cf.* Fig.1.b).

BrainVISA cut tool:

- The following protocol instructs the user to cut sulci when necessary. If the section to cut is too small, BrainVISA will not allow the cut to occur. In such cases, label the whole element according to its most dominant trait.

1. **Identify the callosal sulcus:** The callosal sulcus lies directly dorsal to the corpus callosum. *(N.B. In some brains, this sulcus may be too shallow to be segmented by BrainVISA; identify its location based on indentations in the grey-white matter interface just over the corpus callosum).*

2. **Identify the cingulate sulcus:**

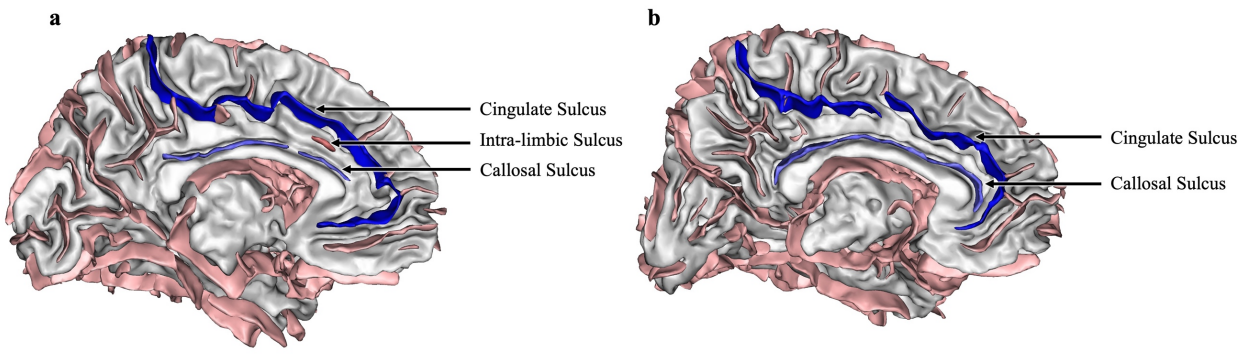

Fig. 2. Examples of cingulate sulci (deep blue). *Continuous (a) and Interrupted (b) cingulate sulci, in left hemispheres in which the callosal and intra-limbic sulci have been labelled.*

The cingulate sulcus (Fig.2) is a primary sulcus and as such is expected to be deep and long. The posterior end of the cingulate sulcus is noticeably located posteriorly from the VPC line, behind the central sulcus, in the mid-sagittal section, with a ventral trajectory at first and curving to an anterior trajectory, predominantly parallel to the callosal sulcus. The cingulate sulcus extends throughout the first quadrant in most cases until at least the genu of the corpus callosum. The cingulate sulcus may be one continuous structure, or it may be interrupted (*i.e.,* split into smaller sections).

2.i. ***Identify the posterior cingulate sulcus element(s)***. Starting posteriorly from the VPC line in the mid-sagittal section, with a ventral trajectory at first and curving to an anterior trajectory, predominantly parallel to the callosal sulcus. Label as cingulate sulcus.

2.ii. ***Identify the anterior cingulate sulcus element(s)*** – in continuity to the posterior cingulate sulcus.
N.B. The cingulate can either be continuous or interrupted:

- *Continuous cingulate:* A continuous cingulate sulcus will run from behind the VPC line through to the genu of the corpus callosum (at least), remaining deep along its path.
- *Interrupted cingulate:* An interrupted cingulate will be composed of separate sulcal elements which together form a sulcal structure resembling a continuous cingulate. Note that merging of sulci including both cingulate and non-cingulate elements can happen and can be identified by noticeable drops in depth along the resulting sulcal combination.

Guidelines:

- *Depth:* Cingulate sulcal elements should be at least half as deep as the deepest sulcus from the first quadrant. If there are noticeable drops in depth within a cingulate sulcal element, consider it as split into two sulci. Consider that the cingulate may have merged either with another cingulate element or with a non-cingulate element, based on the trajectory and depth criteria. If relevant, use the BrainVISA cut tool to separate the elements for accurate labelling.
- *Trajectory:* Once the depth rule is applied, if there is remaining uncertainty, use the trajectory of the sulcal elements to aid the decision. The anterior elements of the cingulate sulcus should globally follow the trajectory of the most ventral part of the posterior cingulate sulcal element (close to the VAC line) and remain predominantly parallel to the callosal sulcus.
- *Vertical Branches:* Vertical branches stemming from the cingulate sulcus/sulcal elements should not be labelled.

3. **Identify whether there are intra-limbic sulci:** If there are sulcal elements located between the cingulate sulcus and the callosal sulcus, label them as intra-limbic sulci (*cf.* Fig.2.a)

4. **Identify whether there is a paracingulate sulcus:**

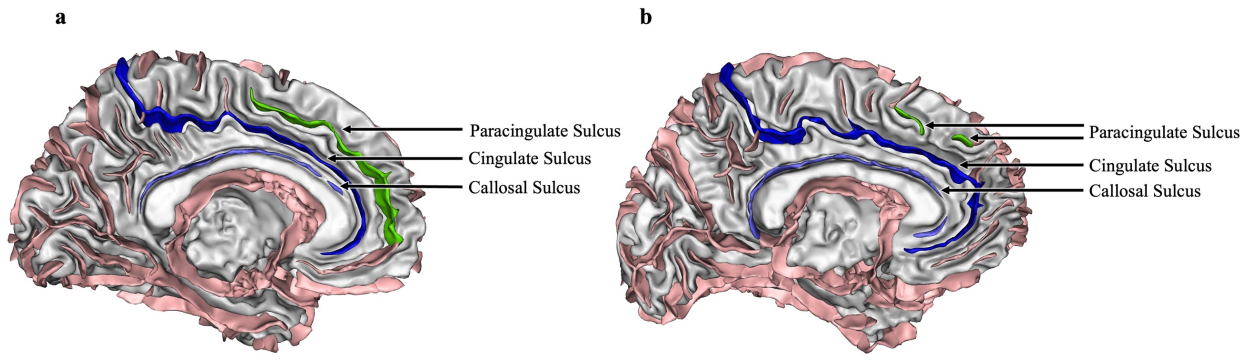

Fig. 3. Examples of paracingulate sulci (green). *Continuous (a) and interrupted (b) paracingulate sulci in left hemispheres in which the callosal and cingulate sulci have been labelled.*

The paracingulate sulcus (Fig.3) is located directly dorsal and parallel to the cingulate sulcus and is oriented with a posterior trajectory. The paracingulate sulcus cannot be present in the absence of a cingulate sulcus. Sometimes the paracingulate sulcus is clear, other times it is completely absent, but it is usually there in part and often interrupted/broken. The paracingulate sulcus/sulcal elements should always move in a posterior direction, towards the back of the brain, and be predominantly parallel to the cingulate sulcus and essentially horizontal. It can help to imagine a vertical line from the horizontal crosshair, and the paracingulate sulcus should move away from this towards the back of the brain.

Start labelling the paracingulate sulcus (or sulcal elements) from the point in the first quadrant where the paracingulate sulcus first moves in a posterior direction. Stop labelling at the VAC line, except if the sulcus, or a sulcal element, continuously flows posteriorly beyond the VAC line – in this case, stop labelling at the point where the sulcus is no longer parallel to the cingulate sulcus and stops having a posterior trajectory. Do not include any elements that start posterior to the VAC line.

Guidelines:

- *Inclusion:* Do not include any sulcal elements that are vertical or do not have a posterior trajectory unless these elements are parallel to the cingulate sulcus.
- *Orientation:* In case of doubt on orientation, rely on the orientation of the indentations in the grey-white matter interface embedding the sulcal element.
- *Branches:* Do not include any branches stemming out from the paracingulate sulcus/sulcal elements.
- *Change in trajectory:* In case of change of trajectory within a sulcal element, cut it and only label the section with the posterior trajectory.

N.B. in cases of uncertainty when labelling any sulci, reference to the raw T1 image may be helpful.

Key changes from Garrison, 2017

- The original protocol specified that the total distance between paracingulate sulcus elements should be no more than 2cm. This rule has been removed, as it resulted in visually analogous sulcal elements being labelled differently depending on their spacing with anterior paracingulate sulcus elements. As a result, i) previously discarded elements are now included in the paracingulate sulcus, and ii) the paracingulate sulcus's configuration may now be sparse.
- The current protocol guides the reader through labelling sulci in the cingulate region in a specified order to improve the accuracy and consistency of paracingulate sulcus identification.
- The current protocol acknowledges the potential presence of intra-limbic sulci.
- As the current protocol utilises 3D visualisations of sulci, it allows the reader to use depth as a criterion for cingulate sulcus identification.

Garrison, J. (2017). *Paracingulate Sulcus Measurement Protocol.* Apollo - University of Cambridge Repository. https://doi.org/10.17863/CAM.9986