



Main anatomical features of the calcarine sulcus: a 3D magnetic resonance imaging at 3T study

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Abstract

Objective The purpose of our study was to determine the main anatomical features of the calcarine sulcus using a 3-T MRI.

Methods Fifty human brains have been explored using an MRI 3-T in Doctors Center in Beirut (Lebanon).

Results The calcarine sulcus was identified in 100% of cases. In most cases, it had a continuous aspect with several peaks. In all our specimens, the calcarine sulcus crosses the parieto-occipital fissure. The majority of their collateral branches and their connections with other sulci were located at the level of the calcarine sulcus properly. In the majority of specimens, the deepest part of the anterior calcarine sulcus forms a protrusion in the occipital horn of the lateral ventricle called calcar avis.

Conclusion Our study emphasizes the fact that the course patterns of the calcarine sulcus are highly variable. The description of the main anatomical features of the calcarine sulcus obtained from our study can be used as a reference for fMRI exploration and is useful for brain surgery.

Keywords Occipital lobe · Calcarine sulcus · Striate cortex · Magnetic resonance imaging

Introduction

The calcarine sulcus is the most reliable anatomic landmark of the medial part of the occipital lobe. This sulcus begins over the splenium of the corpus callosum and continues posteriorly as a gentle and superior convex curvature superiorly surmounted by the parieto-occipital fissure. Appearing during the fourth and fifth months of gestation, this sulcus, considered as intermediate, is subject to numerous variations [19, 20]. The main anatomical descriptions of the calcarine sulcus were previously described in studies conducted solely on the anatomy of the cerebral cortex [1, 11, 17, 19]. Thus, there are very few precise and detailed anatomical data about the calcarine sulcus [14]. Moreover, the majority of descriptions result from cadaveric dissection, not always adapted to clinical and MRI practice.

The purpose of this study was to determine the main anatomical features of the calcarine sulcus using a 3D MRI study at 3-T.

Subjects and method

Subjects

Fifty healthy volunteers (100 hemispheres, left and right), aged 18 to 40 years, with a male to female ratio of 1:1, mean age 27 years, were enrolled in this study. Our exclusion criteria were subjects suffering from neurological or psychiatric disorders and/or at risk of an encephalic lesion during MRI.

MRI data acquisition

MRI was performed with the use of a 3-T MR system (Verio Siemens system) located at the Doctors Center of Beirut (Lebanon). High-resolution 3-dimensional sagittal T1-weighted images were acquired using an MPRAGE sequence of 1 mm slice with reconstruction in axial and coronal planes with the following parameters: TR: 900 ms; TE: 2.49 ms; TI: 900 ms; Flip angle = 9°; 1 mm isotropic voxel. All the MRI images obtained were imported into a

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computer system to be analyzed using post-processing software (Osirix 64).

MRI interpretation

In this study, we used the definition of the calcarine sulcus described by Duvernoy [8], which distinguishes three segments (Fig. 1):

- An anterior segment, the anterior part of the calcarine sulcus, situated beyond the junction with the parieto-occipital fissure. It is the only segment of the calcarine sulcus to be part of the limbic fissure.
- A middle segment, the calcarine sulcus proper, usually has a sinuous aspect.
- A posterior segment, the retro-calcarine sulcus, is formed by the calcarine sulcus when its branches off caudally into two rami, ascending and descending.

By analyzing the post-processed MRI images, the main anatomical features of the calcarine sulcus determined were:

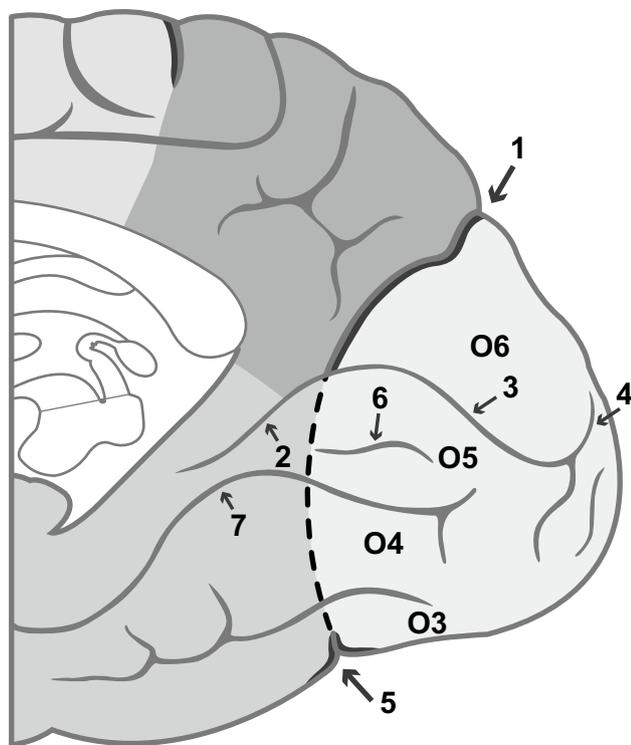


Fig. 1 The three segments of the calcarine sulcus according to Duvernoy (8). 1—Parieto-occipital fissure. 2—Anterior part of the calcarine sulcus. 3—Calcarine sulcus proper. 4—Retro-calcarine sulcus, ascending and descending rami. 5—Temporo-occipital fissure. 6—Lingual sulcus. 7—Collateral sulcus (medial occipitotemporal sulcus). O3: Third occipital gyrus. O4: Fourth occipital gyrus. O5: Fifth occipital gyrus (*Lingual gyrus*); O6: Sixth occipital gyrus (*Cuneus*)

The rate of its presence

The number of convex peak upward existing on its course.

Its continuous or discontinuous character.

The rate of its intersection with the parieto-occipital fissure and the location of this intersection in the coronal plane compared to the origin of the occipital horn of the lateral ventricles, as well as its position compared to the first dome of the calcarine sulcus in the sagittal plan.

The rate and the location of the collateral branches on its course.

The rate of connection with the neighboring sulcus: collateral sulcus (medial occipitotemporal sulcus), paracalcarine sulcus defined as the parallel sulcus of the calcarine sulcus situated in O6 (cuneus), lingual sulcus defined as the parallel sulcus of the calcarine sulcus situated in O5 (lingual gyrus) (Fig. 1).

The end of calcarine sulcus regarding the type of termination and its location on the medial or the lateral face of the occipital lobe.

The rate of the prominence of the anterior part of the calcarine sulcus within the lumen of the occipital horn of the lateral ventricles, in a convex aspect at the inside and concave on the outside, giving birth to the calcar avis.

Using a measurement tool, we have determined the length and the depth of the calcarine sulcus. For the length, using the sagittal plane, we placed the cursor all along the calcarine sulcus and moved step by step, tracing the various curves to obtain the most exact measurement possible. For the depth, using the coronal plane, the distance between the deepest point of the calcarine sulcus and the interhemispheric line was calculated using the cursor.

Results

Overall, the calcarine sulcus was identified in 100% of the cases, mainly with the use of the sagittal plane. The course patterns of the whole calcarine sulcus were characterized by a single peak in 50%, whereas 35% had two and 3% had three peaks (Fig. 2). In the remaining 12% of cases, it had a straight aspect without a peak. In these cases, the parieto-occipital fissure terminates at the junction between the anterior third and the posterior two thirds of the calcarine sulcus. Most frequently (87%), the calcarine sulcus was continuous. Interruptions were present all along its course in the 13% remaining (Fig. 3).

In all of the hemispheres, the inferior end of the parieto-occipital fissure joined the calcarine sulcus:

At the top of the first peak (15%)

Anterior to the first peak (81%) (Fig. 2)

Posterior to the first peak (4%)

This intersection had different locations relative to the origin of the occipital horn of the lateral ventricle: in 68%

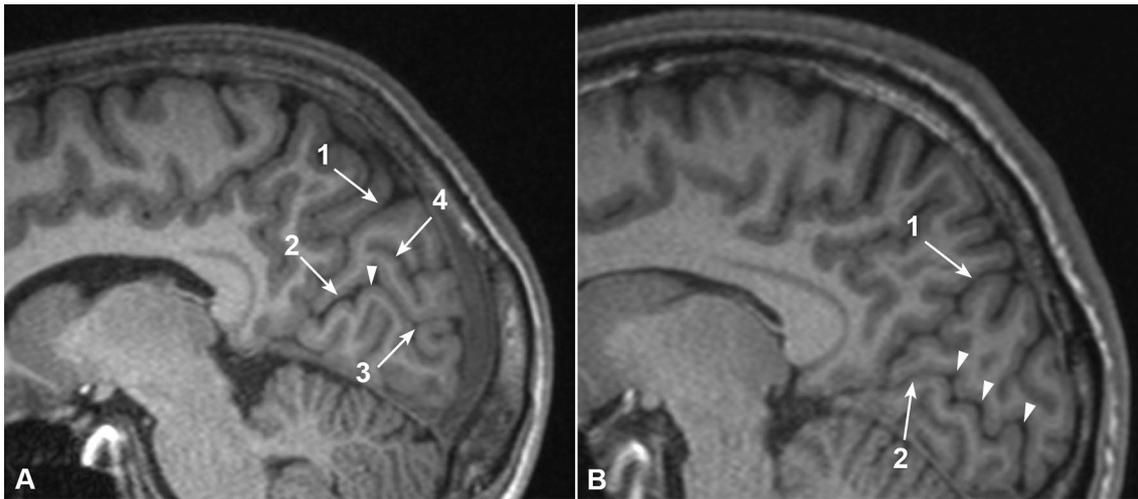


Fig. 2 Number of peaks along the calcarine sulcus course. **a** One peak (white arrow); **b** three peaks (white arrowheads). 1—Parieto-occipital fissure. 2—Calcarine sulcus proper. 3—Retrocalcarine sulcus with its ascending and descending rami. 4—Paracalcarine sulcus



Fig. 3 Sagittal MRI showing. **a** Discontinuous character of the calcarine sulcus; **b** collateral branches along its course (white arrowheads). 1—Parieto-occipital fissure. 2—Anterior part of the calcarine sulcus. 3—Calcarine sulcus proper

of the hemispheres, it was at the level of the occipital horn, in 20% anteriorly and in 12% posteriorly.

In the sagittal plane, the anterior part of the calcarine sulcus described a slightly ascending backwards course in 94% of the cases, whereas it ran straighter in the rest (6%). The calcarine sulcus proper had a sinuous aspect describing a superior convex curvature in all cases.

The retro-calcarine sulcus was clearly formed by two rami, ascending and descending, in 80% of the hemispheres (Fig. 2), whereas in the other 20%, the ascending ramus was absent. Posteriorly, in 69% of the cases, the retro-calcarine sulcus crossed the margin of the hemisphere and extended

along the occipital pole to the lateral surface of the cerebral hemisphere.

In 68% of hemispheres, the calcarine sulcus presented collateral branches more frequently located behind the intersection with the parieto-occipital fissure (75%) (Fig. 3).

Adjacent to the calcarine sulcus, a paracalcarine sulcus (Fig. 2), was identified in 98% of the hemispheres. It joined the calcarine sulcus in 41% of cases. The junction was located at the top of the superior convex curvature in half of cases.

The lingual sulcus was present in 76% of cases. It joined the calcarine sulcus in 21%. The collateral sulcus that was

always present had, in 8% of the cases, connections with the calcarine sulcus.

Calcar avis was identified in 88% of the hemispheres in the occipital horn as a convex aspect to the inner horn (Figs. 4, 5).

The mean length of the calcarine sulcus was 7 cm (5.6–9) and the mean depth was 2 cm (1.3–2.6).

Discussion

A precise knowledge of the sulco-gyral organization of the medial occipital cortex became important for several operative and functional reasons. Neurosurgeons may need to use the trans-sulcal approaches directly to resect gliomas

or metastases or use the sulci as fundamental anatomical landmarks of the brain to perform an en bloc resection [20, 25]. Moreover, surgeons can use the infero-medial side of the occipital lobe as a pathway for the pineal region approach [4, 22]. In these relatively new field of microneurosurgery, the development and use of the transcisternal, transfissural, and trans-sulcal approaches have established the sulci as fundamental landmarks on the brain surface. Moreover, to reduce the post-operative functional risks, in particular cortical blindness, the surgeons have to know the retinotopic organization of visual cortex around the calcarine sulcus. Recently, a technique called “cortical mapping” was described to localize functional cortical regions of the visual processing under awake brain surgery.

Fig. 4 Coronal MRI passing through the anterior part of the calcarine sulcus (a) and the calcar avis (b). 1—Anterior part of the calcarine sulcus. 2—Occipital horn of the lateral ventricle. 3—Calcar avis

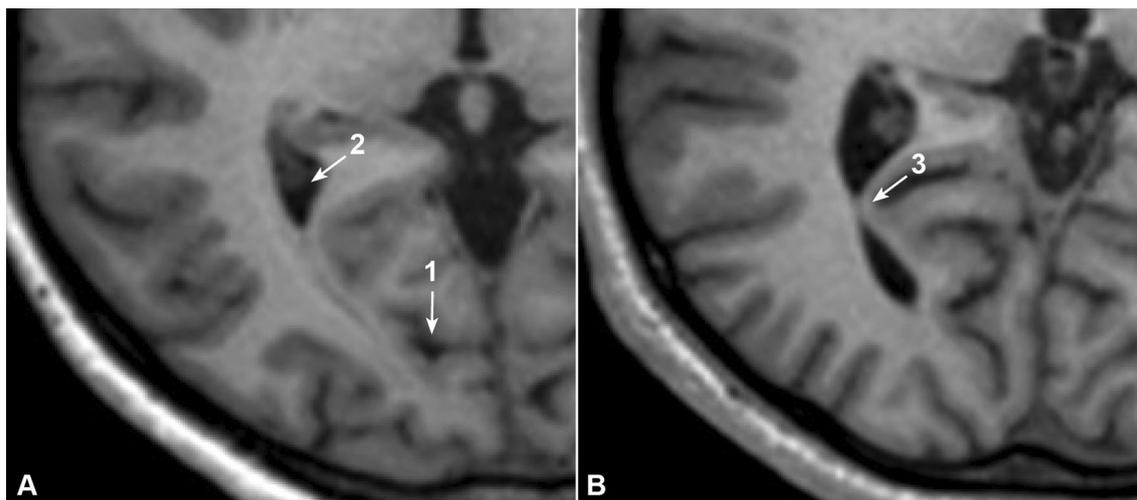
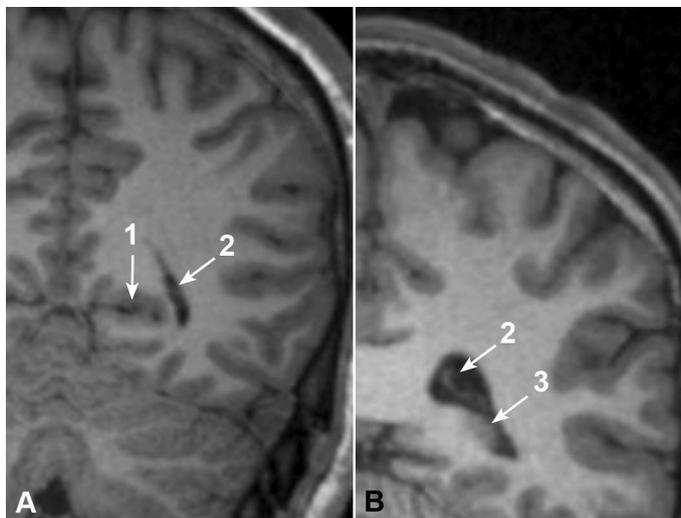


Fig. 5 Horizontal MRI showing the calcarine sulcus (a) and the calcar avis (b). 1—Calcarine sulcus. 2—Occipital horn of the lateral ventricle. 3—Calcar avis

Currently, the fMRI technique has become the preferred method for retinotopic mapping [2, 9, 15, 24]. During the protocols of analysis of the fMRI images, the delineation of regions of interest is not always defined with enough anatomical precision. However, clear and simple methods of manual analysis were proposed to identify main sulci and gyri of cerebral cortex of human brain [5].

Moreover, most of time, the sulco-gyral variations are not taken into account even if these anatomical features have functional consequences [2]. Concerning the occipital lobe, the largest number of variations is observed within the lateral surface [1, 17]. Nevertheless, in spite of its constant presence, the morphological patterns of the calcarine sulcus also vary and only a few studies describe this sulcus in detail [13, 14, 23]. Only one study investigated the calcarine sulcus focusing on its depth and prominent calcar avis [21].

To better understand the detailed anatomy of calcarine sulcus, we carried out a 3T-MRI study in 50 young, healthy subjects. We aim at supplying an exhaustive anatomical description of the calcarine sulcus useful in daily clinical practice and completing the practical guidelines already described [5].

We have chosen to consider only mature mid-life brains (mean age 27 years), to avoid brain atrophy or other age-related abnormalities. Because of potential anatomical brain changes related to schizophrenia or bipolar disorders, patients with psychiatric history were also excluded [6]. The use of 3D MPRAGE sequences at 3-T-MRI allowed us to obtain high-quality images [10]. The post-processing procedure was designed for the most accurate identification of anatomic structures. In literature, the calcarine sulcus was described in a different way. A frequent description divides it into proximal and distal parts, using its junction with the parieto-occipital fissure [20]. In this study, we used the definition suggested by Duvernoy [8] and approved by others [5] who divided it into three segments: (1) a middle corrugated segment, named the calcarine sulcus proper, extending forward to (2) the anterior calcarine sulcus and backward to (3) the vertical retro-calcarine sulcus [8]. This detailed definition seems to be more useful for a functional approach, in particular to identify the anterior calcarine part belonging to the limbic sulcus. Moreover, this definition allows for a better consideration of the primary visual cortex distribution, for which the calcarine sulcus represents the horizontal azimuth [18]. Our study highlights the course patterns and the peak variations of calcarine sulcus.

We can confirm that the presence of a single peak is the most frequent configuration, whereas the presence of three successive peaks is the rarest [17]. Regarding the single-peak configuration, the percentage observed is slightly higher in this study (50% vs 35%) [17]. The number of peaks participates in the configuration of O5 and O6 gyri cortical surfaces.

The inferior end of the parieto-occipital fissure may join the calcarine sulcus at different levels. The junction point is usually defined with regard to the first peak of the calcarine sulcus. In this study, the junction of these two sulci was more often located in front of the first peak, unlike Ono's results [17]. This junction defines the anterior part of the calcarine sulcus and determines its length. In this study, on the opposite side of the calcarine sulcus, the frequency of the passage of the retro-calcarine part from the medial face to the lateral face of the occipital lobe is similar to other studies [16, 17].

Concerning the continuous character, data in literature varies [1, 14, 17]. Our results confirm a low rate of interruptions along the course of the calcarine sulcus. Some of these interruptions correspond to crossing cortical bridges. Those of them passing through the calcarine sulcus to join O5 and O6 were named cuneo-lingual gyrus by Duvernoy [8]. These kinds of bridges increase the cortical surface area in a highly functional region. They may induce a variable distribution of the projection of central vision in the deep part of the calcarine sulcus.

The mean length of the calcarine sulcus was higher in this study (7 cm) than in others (5.8 cm) [11]. Nevertheless, the measuring procedure varies from study to study. Most of the authors measured the sulcus according to a straight line. The sinuous aspects were not taken into account. We have chosen to measure the whole sulcus including its peaks. In the literature, the mean value of the depth of the calcarine sulcus varied between 1 and 3 cm [14]. In this study, the mean value was 2 cm. These morphologic variations are important to consider. Depth and length of the calcarine sulcus vary independently in the brain. Different degrees of folding may cause variability in architectonic areas [7]. Moreover, according to Gilissen et al., the projection area of the mesial cortical surface of the occipital lobe correlates with the length of the calcarine sulcus [12].

Although the collateral sulcus was always present, its connection rate with the calcarine sulcus was only 8%, a lower rate than usually reported [17]. The paracalcarine sulcus was almost always present in this study. In 41% of cases, it was connected with the calcarine sulcus, much higher than previously reported [17]. Finally, for the lingual sulcus, the connection rate with the calcarine sulcus was equivalent to the previous observations (around 20%) [17].

In this study, the calcar avis, defined as the prominence of the anterior part of the calcarine sulcus in the inner wall of the occipital horn of the lateral ventricle, is observed in 88% of the cases, just as described in Ribas study [19], but more than that described in Savas study 24% [21]. The presence of calcar avis in the ventricular lumen constitutes a useful anatomical reference for neurosurgeons, especially during intraventricular endoscopy.

A large percentage of the collateral branches presence on the course of the calcarine sulcus gives them a functional

value regarding the precise distribution of the visual areas. It seems to us important to know that the retro-calcarine sulcus, surrounded by the cortical area of central vision, can cross the margin of the hemisphere and extend along the lateral surface of the occipital pole [19].

Similarly, its constant origin with its significant variation in length in a highly functional region as the limbic region must have functional consequences. In classic anatomical studies, the anterior part of the calcarine sulcus is described as the boundaries between the limbic cortex lying on the isthmus and the striate cortex found only on ventral edge of the calcarine sulcus [3].

Therefore, this can be an argument that the real origin of the calcarine sulcus is in the para-hippocampal region, knowing that the anterior calcarine sulcus is a part of the calcarine sulcus.

This study highlights the anatomical variability of course, form, collateral branches of the calcarine sulcus and its numerous connections with the various neighboring sulci. Most of these findings may help us to explain the diversity of the clinical manifestations and clinical recovery rate for topographically similar lesions. This study allows a more precise and relevant reading of the fMRI.

Author contributions Research strategy: AREM. Data analysis: TM, FV, LT.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Alves RV, Ribas GC, Parraga RG, de Oliveira E (2012) The occipital lobe convexity sulci and gyri. *Laboratory investigation. J Neurosurg* 116(5):1014–1023
- Arcaro MJ, McMains SA, Singer BD, Kastner S (2009) Retinotopic organization of human ventral visual cortex. *J Neurosci* 29(34):10638–10652
- Bolton JS (1900) The exact histological localisation of visual area of the human cerebral cortex. *Philos Trans R Soc Lond Ser B* 193:165–222
- Dandy WE (1936) Operative experience in cases of pineal tumors. *Arch Surg* 33:19–20
- Destrieux C, Terrier LM, Andersson F et al (2017) A practical guide for the identification of major sulcogyral structures of the human cortex. *Brain Struct Funct* 222:2001–2015
- Donohoe G, Frodl T, Moris D et al (2010) Reduced occipital and prefrontal brain volumes in dysbindin-associated schizophrenia. *Neuropsychopharmacology* 35(2):368–373. <https://doi.org/10.1038/npp.2009.140>
- Dupont P, Orban GA, Debruyn B et al (1994) Many areas in the human brain respond to visual motion. *J Neurophysiol* 72:1420–1424
- Duvernoy HM (1999) *The human brain: surface, blood supply, and three-dimensional sectional anatomy*. Springer, New-York
- Engel SA, Glover GH, Wandell BA (1997) Retinotopic organization in human visual cortex and the spatial precision of functional MRI. *Cereb Cortex* 7(2):181–192
- Flakovskiy P, Brenner D, Feiweier T et al (2016) Comparison of accelerated T1-Weighted whole-brain structural-imaging protocols. *Neuroimaging* 124:157–167
- Flores LP (2002) Occipital lobe morphological anatomy: anatomical and surgical aspects. *Arq Neuropsiquiatr* 60(3-A):566–571
- Gilissen E, Iba-Zizen MT, Stievenart JL et al (1995) Is the length of the calcarine fissure associated with the size of the human visual cortex? A morphometric study with magnetic resonance tomography. *J Hirnforsch* 36(4):451–459
- Iara G, Petrides M (2007) Occipital sulci of the human brain: variability and probability maps. *J comparative Neurol* 501:243–259
- Korogi Y, Tkahashi M, Okuda T et al (1996) MR tomography of the striate cortex: correlation with anatomic sections. *Int J Neuroradiol* 2:534–540
- Kwong KK, Belliveau J, Chesler D et al (1992) Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation. *Proc Natl Acad Sci USA* 89:5675–5679
- Malikovic A, Vucetic B, Milisavljevic M et al (2012) Occipital sulci of the human brain. *Variability Morphometry Anat Sci Int* 87(2):61–70
- Ono M, Kubik S, Abernathy (1990) *Atlas of the cerebral sulci*. Thieme, Stuttgart
- Rajimehr R, Tootel Roger BH (2009) Does retinotopy influence cortical folding in primate visual cortex? *J Neurosci* 29(36):11149–11152
- Ribas GC (2010) The cerebral sulci and gyri. *Neurosurg Focus* 28(2):E2. <https://doi.org/10.3171/2009.FOCUS09245>
- Ribas GC, Yasuda A, Ribas EC et al (2006) Surgical anatomy of micro neurosurgical sulcal key-points. *Neurosurgery* 59(4 suppl 2):ONS177–ONS210 (**discussion ONS210-1**)
- Savas R, Sener RN (1998) Deep calcarine sulcus and prominent calcar avis. *J Neuroradiol* 25:144–146
- Schimidek HH (1992) Surgical management of supra tentorial glioma. In: Schimidek HH (ed) *Operative neurosurgical techniques*, 3rd edn, vol 1. Saunders, Philadelphia, pp 517–535
- Steinmetz H, Furst G, Freund H (1989) Cerebral localization application and validation of the proportional grid system in MR imaging. *J Comput Assist Tomogr* 13:10–19
- Wu J, Yan T, Zhang Z et al (2012) Retinotopic mapping of the peripheral visual field to human visual cortex by functional magnetic resonance imaging. *Hum Brain Mapp* 33:1727–1740
- Yasargil MG (1999) A legacy of micro neurosurgery: memoirs, lessons, and axioms. *Neurosurgery* 45:1025–1092