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ORIGINAL ARTICLE

Mapping the superficial morphology of the occipital lobe: proposal of a universal nomenclature for clinical and anatomical use

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Abstract

The superficial anatomy of the occipital lobe has been described as irregular and highly complex. This notion mainly arises from the variability of the regional sulco-gyral architecture. Our aim was to investigate the prevalence, morphology, and correlative anatomy of the sulci and gyri of the occipital region in cadaveric specimens and to summarize the nomenclature used in the literature to describe these structures. To this end, 33 normal, adult, formalin-fixed hemispheres were studied. In addition, a review of the relevant literature was conducted with the aim to compare our findings with data from previous studies. Hence, in the lateral occipital surface, we recorded the lateral occipital sulcus and the intraoccipital sulcus in 100%, the anterior occipital sulcus in 24%, and the inferior occipital sulcus in 15% of cases. In the area of the occipital pole, we found the transverse occipital sulcus in 88% of cases, the lunate sulcus in 64%, the occipitopolar sulcus in 24%, and the retrocalcarine sulcus in 12% of specimens. In the medial occipital surface, the calcarine fissure and parieto-occipital sulcus were always present. Finally, the basal occipital surface was always indented by the posterior occipitotemporal and posterior collateral sulci. A sulcus not previously described in the literature was identified on the supero-lateral aspect of the occipital surface in 85% of cases. We named this sulcus "marginal occipital sulcus" after its specific topography. In this study, we offer a clear description of the occipital surface anatomy and further propose a standardized taxonomy for clinical and anatomical use.

Keywords Occipital surface anatomy · Occipital lobe · Sulci · Gyri · Brain anatomy

Introduction

The occipital lobe has attracted particular scientific interest since the second half of the 19th century. Indeed, different techniques have been implemented to approach the anatomo-functional correlates of this highly eloquent area. Initially, Brodmann (1909), Economo and Koskinas (1925) focused on the cytoarchitectonic organization. The classification of the occipital cortex into Brodmann areas 17, 18, and 19 applies to date [4]. During the following years, neurophysiological studies in non-human primates picked up the torch. These studies identified distinct functional units in the occipital cortex. In the era of functional imaging, the interest shifted towards the delineation of equivalent areas in the human brain. This led to the identification of analogous areas in the human occipital lobe and to the notion that no strict anatomo-functional correlation exists [3, 33, 36, 37].

Cunningham and Elliot Smith were the first to conduct anatomical studies during the late 19th and early 20th

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century[7, 34]. For many decades, the efforts to achieve a more precise understanding of the anatomy of the occipital lobe were mainly limited to the description of the most prevalent landmarks such as the calcarine fissure and the parieto-occipital sulcus. In the mid and late 20th century, less prominent structures such as the lunate sulcus which corresponds to the Affenspalte of the non-human primate brain drew special attention [6]. It was not until 1990 that Ono and colleagues presented a detailed description of the occipital area in their textbook "Atlas of the cerebral sulci" [27]. Since then a limited number of studies attempted to systematically record and categorize the morphological features of the occipital region.

However, the available literature on the surface morphology of the occipital lobe remains vague on mainly two topics. First, there is a lack of a unified classification and universally accepted definitions, as is the case in the frontal, temporal, and parietal areas. This is evident in modern neuroanatomical textbooks that are devoid of a thorough description of this area referring to it as irregular and highly variable. Second, the nomenclature used in different studies regarding the occipital region is often inconsistent, overlapping, and conflicting and thus creates further confusion to the reader.

We therefore set out to accomplish a systematic and detailed description of the morphology and topography of the occipital lobe through a focused anatomic study and to compare our findings to current literature with the overarching goal to pave the way for a universally accepted terminology for clinical and anatomical use.

Methods

33 adult, cadaveric hemispheres (16 right, 17 left) fixed in a 15% formalin solution for two (2) months were studied. The hemispheres came from 17 individuals (10 male/7 female) aged between 42 and 74 yeas (average 58) with no history of neurological disease. The arachnoid membrane and vessels of the area of the occipital lobe were cautiously removed under the microscope (Carl Zeiss OPMI) and the sulcal and gyral morphology was systematically recorded in 4 different areas: the occipital pole, the lateral surface, the medial surface, and the basal surface of the occipital lobe. Using a Nikon DSLR camera and a macro lens, we obtained multiple photographs from different angles to vividly illustrate the regional surface anatomy. The prevalence, topography, morphology, branching pattern, and correlative anatomy of the sulco-gyral structures were meticulously recorded. We furthermore went on and reviewed the relevant literature, mainly focusing on modern studies conducted during the past 30 years. The variable and inconsistent anatomical nomenclature used for the sulco-gyral pattern of the occipital lobe was documented with the aim to detect the misaligning or overlapping terminologies and to propose a standardized taxonomy.

Results

The superficial morphology of the occipital lobe was categorized into four different sub-regions based on the findings of previous studies, allowing for a better understanding of the most prominent and consistent anatomical landmarks of this highly variable area. Our results are summarized in Table 1.

(1) Area of the occipital pole

The occipital pole represents the most posterior aspect of the hemisphere and the area of convergence of the superior and inferior occipital gyri. The distance measured between the occipital pole and the preoccipital notch varied from 40 to 56 mm (average 48 mm). Four sulci and one gyrus were systematically recorded in the area of the occipital pole (Fig. 1).

More specifically:

Lunate sulcus

The lunate sulcus is a crescent-shaped, vertical-oriented sulcus with its concavity facing the occipital pole. It was recorded in 64% (21/33) of the specimens. In 54% (18/33) of them, it was identified as a deep and continuous sulcus while in 9% (3/33), it was interrupted and shallow. In 6% (2/33) of cases, it was seen to originate either from the inferior part of the transverse sulcus or from the posterior part of the lateral occipital sulcus. In 9%, the lunate sulcus gave rise to a small branch, which was seen to run posteriorly and perpendicular to the main stem. This branch typically emerged from the mid-portion of the lunate sulcus. In 6% (2/33) of the hemispheres, the sulcus was encountered on the basal occipital surface.

Transverse occipital sulcus

The transverse occipital sulcus is a relatively constant (present in 29/33 of the studied hemispheres) vertical sulcus, typically arising at the end of the intraoccipital sulcus. The intraoccipital-transverse sulcal meeting point divides this sulcus into a superior and inferior segment. The mean length of the superior and inferior sulcal segments was 19 mm and 21 mm, respectively. In 60% of cases, the sulcus did not exhibit any branches, while in 40%, it was recorded to have 1 to 4 branches running

Table 1 Findings of the current study

Key anatomical landmarks of the occipital lobe					
Structure	Consistency	Lateralization	Mean length (mm)	Branching pattern	Additional information
Occipital pole					
Lunate sulcus	64%	No	22	0–1 branches	May merge with transverse sulcus or lateral occipital sulcus
Transverse occipital sulcus	88%	No	41	1–4 branches (40%)	Intersected by intraoccipital sulcus
Retrocalcarine sulcus	12%	Left (75%)	11	–	Arises from calcarine fissure
Occipitopolar sulcus	24%	No	7	–	–
Gyrus descendens	9%	No	–	–	Delineated by retrocalcarine sulcus posteriorly and occipitopolar sulcus anteriorly
Occipital convexity					
Intraoccipital sulcus	100%	No	25	0–3	Bisects transverse sulcus
Lateral occipital sulcus	100%	No	42	1–4	Posterior end merges with inferior transverse sulcus (12%) or lunate sulcus (10%)
Inferior occipital sulcus	15%	Left (60%)	27	1–4	Parallel and ventral to lateral occipital sulcus
Anterior occipital sulcus	24%	Right (75%)	19	–	Intersected by lateral occipital sulcus (6%)
Superior occipital gyrus	100%	No	–	–	Delineated by superior aspect of the hemisphere superiorly and intraoccipital sulcus or lateral occipital sulcus inferiorly
Middle occipital gyrus	88%	No	–	–	Delineated by intraoccipital sulcus superiorly and lateral occipital sulcus inferiorly. May be divided by middle occipital sulcus
Inferior occipital gyrus	100%	No	–	–	Delineated by lateral occipital sulcus superiorly and occipitotemporal sulcus inferiorly. May be divided by inferior occipital sulcus
Medial occipital surface					
Calcarine fissure	100%	No	73	1–5 paracalcarine sulci	Divided by parieto-occipital sulcus into proximal and distal part
Parieto-occipital sulcus	100%	No	49	1–5 (82%)	–
Superior sagittal cuneal sulcus	67%	No	–	–	Parallel and dorsal to calcarine fissure. Sometimes arises from the latter
Inferior sagittal cuneal sulcus	24%	No	–	–	May be parallel or perpendicular to the parieto-occipital sulcus
Marginal occipital sulcus	85%	Right (61%)	33	–	May be longitudinal, T-shaped, or H-shaped
Lingual gyrus	100%	No	–	–	Delineated by calcarine fissure superiorly and posterior collateral (or its dorsal ramus) inferomedially
Basal occipital surface					
Posterior occipitotemporal sulcus	100%	No	35	1–4 branches (1 branch pattern in 82%)	In 24%, the posterior occipitotemporal sulcus intersected the collateral sulcus
Posterior collateral sulcus	100%	No	22	May divide into superior and inferior terminal branch in 33%. May give rise to 1–8 smaller branches	–

perpendicular to the main stem and usually merging with the lunate or the marginal occipital sulcus. The transverse occipital sulcus was observed to intersect the lateral occipital sulcus in 12% (4/33) and the lunate

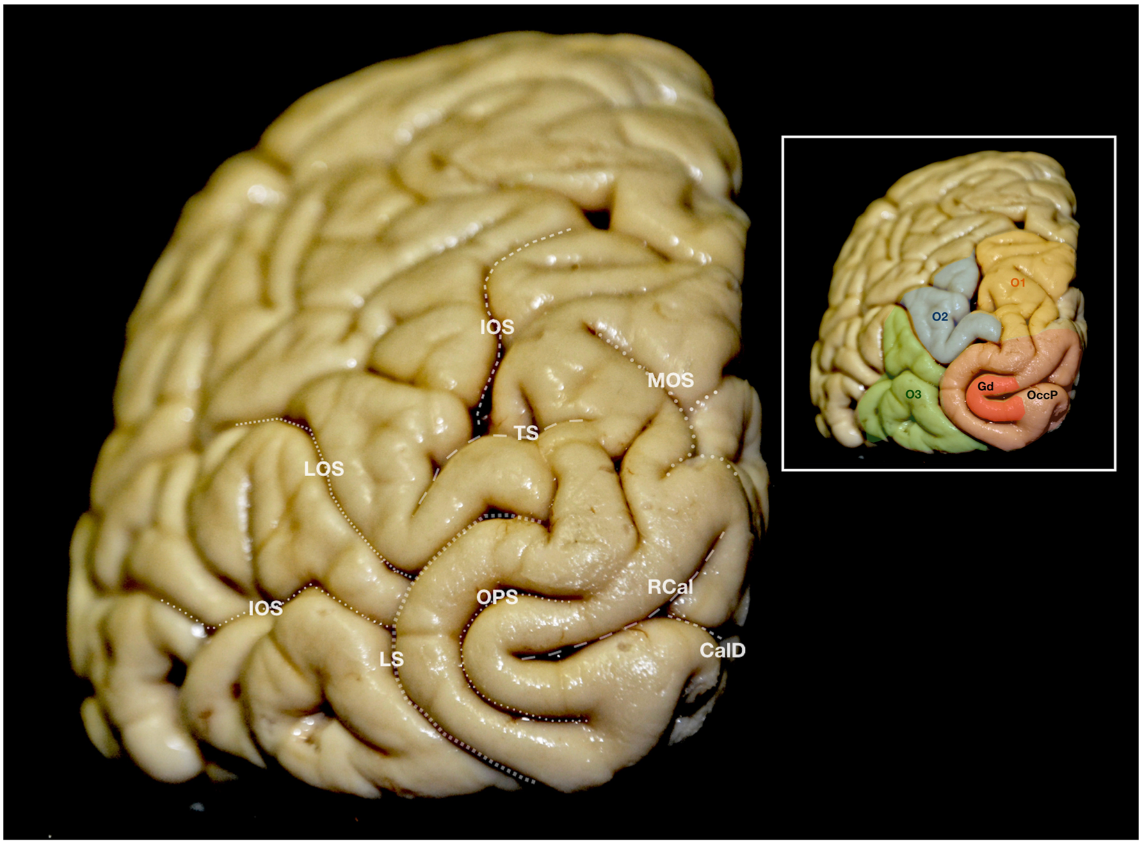

Fig. 1 Surface anatomy of the occipital pole. A posterior view of a left cerebral hemisphere illustrating the superficial anatomy of the occipital pole. The bifid termination of the calcarine sulcus, namely the retrocalcarine sulcus, can be identified. Anterior to the retrocalcarine sulcus, the occipitopolar, lunate, and transverse sulci are demarcated with their concavities facing towards the pole. The marginal occipital, intraoccipital, lateral occipital, and inferior occipital sulci are also illustrated. Inset: The gyral morphology on the same specimen is illustrated. The superior (O1), middle (O2), and inferior occipital gyri are highlighted in orange, blue, and green color, respectively. The area of the occipital pole is highlighted in light orange color. The gyrus descendens, delineated by the occipitopolar and retrocalcarine sulci, is highlighted in dark orange color. CalD = distal part of the calcarine sulcus; GD = gyrus descendens; IOS = inferior occipital sulcus; LOS = lateral occipital sulcus; LS = lunate sulcus; MOS = marginal occipital sulcus; O1 = superior occipital gyrus; O2 = middle occipital gyrus; O3 = inferior occipital gyrus; OccP = occipital pole; OPS = occipitopolar sulcus; RCal = retrocalcarine sulcus; TS = transverse occipital sulcus

sulcus in 3% (1/33) of the hemispheres. It was seen to extend to the superomedial aspect of the occipital lobe in 6% of cases (2/33).

Retrocalcarine sulcus

This sulcus appears as the terminal bifurcation of the calcarine fissure. It was detected in 12% (4/33) of cases, exhibiting a left side preponderance of 75% (3/4 cases). It was encountered either anterior to the occipital pole on the medial aspect (75%) or at the level of the apex of the occipital pole (25%).

Occipitopolar sulcus

The occipitopolar sulcus was identified in 24% (8/33) of the studied hemispheres. This small crescent-shaped sulcus appears as a short and shallow indentation encountered posterior and parallel to the lunate sulcus.

Gyrus descendens

The gyrus descendens was detected in 9% (3/33) of the hemispheres, when both the retrocalcarine and occipitopolar sulci were present. This gyrus appears as a thin cortical strip between the two aforementioned sulci, lying just anterior to the apex of the occipital pole.

(2) Medial occipital surface

The medial aspect of the occipital lobe is delineated anteriorly by the parieto-occipital sulcus and superiorly by the free margin of the hemisphere (or the marginal occipital sulcus when it is present). Inferiorly, the medial and basal surface of the occipital lobe seem to be in continuity. Therefore, the superior part of the lingual gyrus resides in the medial surface while its inferior part to the basal surface. The medial occipital surface includes the cuneal and lingual gyri. The calcarine fissure and the parieto-occipital sulcus are the most consistent and prominent landmarks in this area (Fig. 2).

Calcarine sulcus

The calcarine sulcus is a consistent sulcus and originates at the level of the isthmus of the cingulate gyrus. It was seen to exhibit a postero-superior trajectory, reaching the area of the occipital pole. Four different morphological patterns were observed (Fig. 6) with the most common being that of an "M shaped" (23/33) or reverse V-shaped (6/33) morphology. An incomplete (1/33) as well as an "S-shaped" (3/33) pattern were also encountered. The calcarine sulcus appeared as a complete and continuous sulcus in 91% (30/33) of the studied hemispheres. In one case, the sulcus was interrupted and consisted of two individual sulci. A number of 1–5 rami were recorded to branch off the stem of the calcarine fissure in 67% (22/33) of the cases. These branches, known as the paracalcarine sulci, travel for a short distance on the lingual and/or the cuneal gyri.

The calcarine sulcus was observed to meet the parieto-occipital sulcus in all studied cases. This sulcal meeting point known as the cuneal point defines the transition between the proximal and distal part of the calcarine sulcus. In 6% (2/33) of cases, the caudal collateral sulcus bents towards and meets the distal part of the calcarine sulcus. In 79% (20/33) of the specimens, the calcarine sulcus reaches and projects to the lateral cerebral surface. In 12% (4/33), it was recorded to

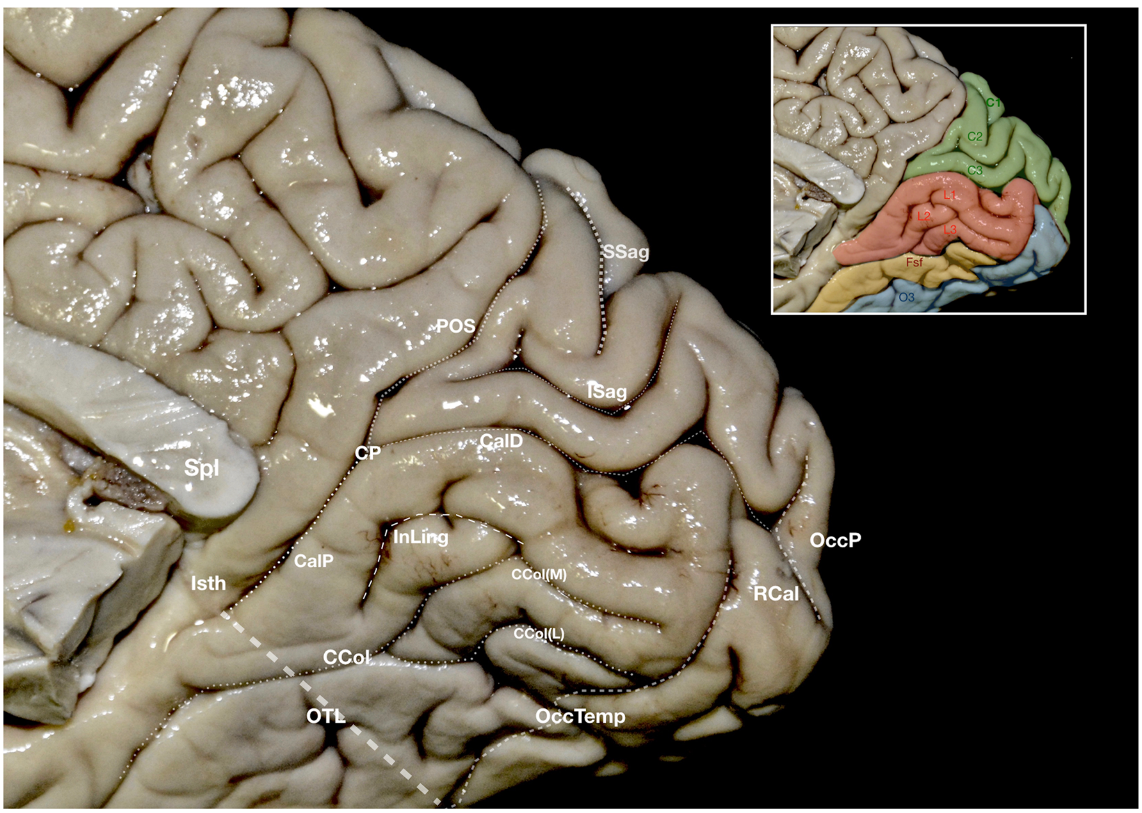

Fig. 2 Surface anatomy of the medial and basal occipital area. Medial view of a right cerebral hemisphere. The occipitotemporal line that is the anterior border of the basal occipital surface, connecting starting point of the proximal part of the calcarine sulcus to the preoccipital notch is illustrated. The parieto-occipital and the calcarine sulci can be easily identified. Their intersection, known as the cuneal point, divides the calcarine sulcus into a proximal and a distal part. A superior and an inferior sagittal sulcus divide the cuneus into three gyri. Inferior to the calcarine sulcus, the lingual gyrus is indented by an intralingual sulcus that arises from the posterior part of the collateral sulcus, namely the caudal collateral sulcus. Lateral to the collateral sulcus, the posterior occipitotemporal sulcus is seen. These two sulci demarcate the fusiform gyrus. Inset: The gyral morphology is illustrated with the green color for the cuneus, red color for the lingual gyrus, orange color for the posterior fusiform gyrus, and blue color for the inferior occipital gyrus (O3). The cuneus is divided by the sagittal sulci into a superior (C1), middle (C2), and inferior (C3) cuneal gyrus. Likewise, the intralingual sulcus divides the lingula into a superior (L1), a middle (L2), and an inferior (L3) lingual gyrus. C1 = superior cuneal gyrus; C2 = middle cuneal gyrus; C3 = inferior cuneal gyrus; CalD = distal part of the calcarine sulcus; CalP = proximal part of the calcarine sulcus; CCol = caudal collateral sulcus; CCol(L) = lateral branch of the caudal collateral sulcus; CCol(M) = medial branch of the caudal collateral sulcus; CP = cuneal point; Fsf = posterior fusiform gyrus; InLing = intralingual sulcus; ISag = inferior sagittal sulcus of the cuneus; Isth = isthmus of the cingulate gyrus; L1 = superior lingual gyrus; L2 = inferior lingual gyrus; O3 = inferior occipital gyrus; OccP = occipital pole; OccTemp = posterior occipitotemporal sulcus; OTL = occipitotemporal line; POS = parieto-occipital sulcus; RCal = retrocalcarine sulcus; Spl = splenium of the corpus callosum; SSag = superior sagittal sulcus of the cuneus

exhibit a bifid termination, giving rise to the retrocalcarine sulcus.

Parieto-occipital sulcus

The parieto-occipital sulcus (POS) is a constant (100% of the studied hemispheres) sulcus, seen to originate in the retrosplenial area. It exhibits a postero-superior trajectory reaching the lateral surface in 91% (30/33) of cases. In 7 hemispheres, the external perpendicular fissure was seen to intersect with the intraparietal-intraoccipital sulcal meeting point. In 82% (27/33) of the specimens, the POS was recorded to exhibit 1 to 5 sulcal branches directed towards the cuneus.

Cuneal sulci

The cuneal sulci were prominent and deep in 91% (30/33) of the specimens while in the remaining 9% (3/33) they were shallow, randomly orientated, and fragmented, thus creating a non-typical anatomy. In 24% (8/33) of the hemispheres, two (2) cuneal sulci were identified whereas in 12% (4/33) three (3) or more sulci were obvious (Fig. 5). The most frequent of these sulci was the inferior sagittal sulcus, which runs parallel and slightly superior to the distal part of the calcarine fissure (Figs. 2 and 5). In one case, this sulcus was seen to emerge as a dorsal branch of the calcarine fissure. The second most consistent sulcus encountered was the superior sagittal sulcus, exhibiting a trajectory that was parallel or oblique with regard to the parieto-occipital sulcus.

Interestingly, in 85% (28/33) of the studied specimens, we identified and recorded, for the first time in the relevant literature, a sulcus seen to run in a parallel trajectory to the interhemispheric fissure and to reside at the margin of the cuneus and the superior occipital gyrus. It exhibits a straight, H-shaped, or T-shaped configuration and its mean length is 33 mm (range 28–37 mm). We named this sulcus the "marginal occipital sulcus" after its specific topography (Fig. 7).

Lingual gyrus

The lingual gyrus is demarcated superiorly by the calcarine fissure and inferiorly by the trunk or the medial branch of the posterior collateral sulcus. In 91% (30/33) of the specimens, the lingual gyrus exhibits a continuous morphology while in 9% (3/33), it was interrupted by 1 or 2 intralingual sulci. When present, these sulci divide the lingual gyrus into a superior and inferior segment (Fig. 2).

(3) Lateral occipital surface

The lateral occipital surface is an area of significant variability. It is demarcated anteriorly by the imaginary line that connects the lateral extension of the parieto-occipital sulcus to the preoccipital notch. Superiorly and inferiorly, it is delineated by the superior and inferior margin of the hemisphere, respectively (Fig. 3).

Intraoccipital sulcus

The intraoccipital sulcus was invariably present. In 88% (29/33) of specimens, it exhibits a continuous trajectory while in the remaining 12% (4/33) an interrupted one. In 85% (28/33) of cases, it was recorded as the direct continuation of the intraparietal sulcus to the occipital area. In the remaining 15% (5/33), the intraoccipital sulcus was seen to branch off the intraparietal sulcus as a separate sulcus. In the majority of cases, the intraoccipital-transverse occipital sulcus meeting point divides the latter into a superior and an inferior segment.

Lateral occipital sulcus

The lateral occipital sulcus was consistently (100% of the specimens) identified as a longitudinal sulcus emerging at the level of the occipitotemporal junction. It was either seen as the continuation of the superior (13/33) or inferior (3/33) temporal sulci or, alternatively as an independent sulcus arising approximately at the level of the angular gyrus in the rest of the cases. In 12% (4/33) of the hemispheres, the posterior segment of the lateral occipital sulcus was found to reach the inferior part of transverse sulcus while in 9% (3/33) of cases, it merged with the inferior part of the lunate sulcus. The lateral occipital sulcus showed up to 4 rami branching off its main stem.

Inferior occipital sulcus

This sulcus was detected in 15% (5/33) of cases, running parallel and ventral to the lateral occipital sulcus. When present, it divides the inferior occipital gyrus into a superior and inferior segment.

Anterior occipital sulcus

The anterior occipital sulcus was seen to run parallel to the arbitrary line that demarcates the occipital lobe and was identified in 24% (8/33) of the studied specimens. In 6% (2/33) of cases, it was observed to meet the lateral occipital sulcus in a sulcal meeting point.

Superior occipital gyrus

The superior occipital gyrus is demarcated by the marginal occipital sulcus (when present) or the free margin of the hemisphere superiorly and inferiorly by the complex of the

Fig. 3 Surface anatomy of the lateral occipital surface. Posterolateral view of a right cerebral hemisphere. The preoccipital notch as well as the external perpendicular fissure demarcate the occipital from the parietal and temporal lobes. The intaparietal–intaoccipital sulcus transition point is defined by the lateral projection of the external perpendicular fissure. The lateral occipital sulcus and the intraoccipital sulcus intersect with the transverse occipital sulcus. The inferior occipital sulcus runs parallel to the inferior margin of the hemisphere and meets the lunate sulcus. Posterior to the lunate sulcus, the occipitopolar and retrocalcarine sulci are identified close to the occipital pole. The anterior occipital sulcus in this specimen is seen to run vertically to the occipitotemporal transition area. Inset: The gyral morphology of the lateral aspect of the occipital lobe is illustrated: The superior (O1), middle (O2), and inferior (O3) occipital gyri are highlighted in yellow, blue, and green color, respectively. The superior (O1) and inferior (O3) gyri can be seen merging in the area of the occipital pole (white arrow), while the middle occipital gyrus presents with a more retracted configuration. AOS = anterior occipital sulcus; EPF = external perpendicular fissure; InOS = inferior occipital sulcus; IOS = intraoccipital sulcus; IPS = intraparietal sulcus; LOS = lateral occipital sulcus; LS = lunate sulcus; OPS = occipitopolar sulcus; PON = preoccipital notch; RCal = retrocalcarine sulcus; TS = transverse occipital sulcus

intraoccipital-transverse occipital sulci. It was usually seen to be traversed by one or more vertical sulcal rami such as the superior transverse sulcus, branches of the marginal occipital sulcus, or the intraoccipital sulcus. The superior occipital gyrus merges posteriorly with the inferior occipital gyrus in the area of the occipital pole.

Middle occipital gyrus

The middle occipital gyrus is bordered by the intraoccipital sulcus superiorly and the lateral occipital sulcus inferiorly. In 70% (23/33) of cases, this gyrus was divided by a middle occipital sulcus into a superior and inferior part. The middle occipital gyrus is bordered posteriorly by the lunate sulcus and therefore does not merge in the area of the occipital pole.

Inferior occipital gyrus

The inferior occipital gyrus is delineated superiorly by the lateral occipital sulcus and inferomedially by the posterior occipitotemporal sulcus. When an inferior occipital sulcus is present (5/33 or 15% of the cases), it splits this gyrus into a superior and inferior part. The inferior occipital gyrus is typically seen to reach the area of the occipital pole, merging with the posterior part of the superior occipital gyrus.

(4) Basal occipital surface

The basal occipitotemporal surface is a large area divided by the arbitrarily defined occipitotemporal line into a temporal and an occipital part. This straight imaginary line connects the starting point of the proximal part of the calcarine fissure to the preoccipital notch [29–32]. The preoccipital notch corresponds to a deep indentation of the inferolateral border of the hemisphere, located approximately 5 cm anterior to the occipital pole and separating the temporal from the occipital lobe [12, 30]. Laterally, the basal occipital surface extends up to the inferior margin of the hemisphere while medially it continues as the medial occipital surface. In this area, two prominent sulci and three gyri can be identified, namely the posterior occipitotemporal sulcus, the posterior collateral sulcus, the ventral aspect of the lingual gyrus, the posterior fusiform gyrus, and the ventral part of the inferior occipital gyrus (Figs. 4, 5, and 6).

Posterior occipitotemporal sulcus

The occipitotemporal sulcus is a constant and prominent horizontal sulcus indenting the basal temporo-occipital surface. It can be divided into an anterior (temporal) and a posterior (occipital) part by the temporo-occipital line. The posterior part had a complete and continuous sulcal trajectory in 67% (22/33) of the specimens while in the remaining 33% (11/33), it was interrupted. In one hemisphere, the occipitotemporal sulcus appeared as the posterior continuation of the inferior temporal sulcus. In 24% (8/33) of cases, the sulcus was seen to deviate medially meeting the caudal collateral sulcus. A maximum of 4 rami were recorded to branch off the sulcus, with the single-branch pattern being the most common one.

Caudal collateral sulcus

The caudal segment of the collateral sulcus runs on the medial aspect of the basal occipital surface. It either travels as a continuous sulcus or it bifurcates into a medial and lateral branch. The "continuous pattern" was seen in 67% (22/33) of the studied hemispheres while the "bifurcated pattern" was

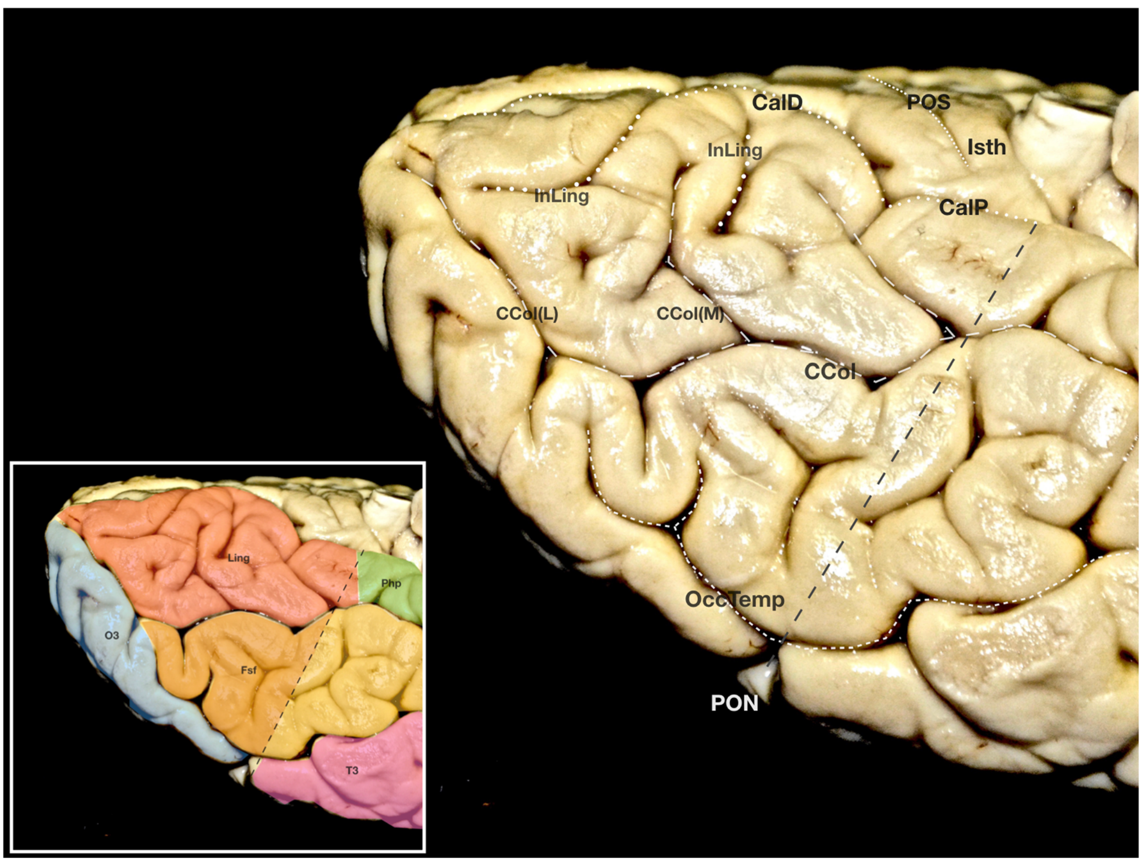

Fig. 4 Standard superficial anatomy of the basal occipital surface. Inferior view of a left cerebral hemisphere. The basal surface of the occipital lobe is anteriorly delineated by the occipitotemporal line (black dashed line) connecting the starting point of the proximal calcarine sulcus to the preoccipital notch. The caudal collateral sulcus gives off a medial and a lateral branch. The posterior occipitotemporal sulcus is seen. In this specimen, two vertical intralingual sulci travel on the surface of the lingual gyrus. Inset: The gyral morphology of the basal temporo-occipital area is illustrated. The lingual gyrus(red), the posterior fusiform gyrus(orange), the inferior occipital gyri(blue), the parahippocampal gyrus(green), the anterior fusiform gyrus (yellow) as well as the inferior temporal gyrus (purple) are depicted. CalD = distal part of the calcarine sulcus; CalP = proximal part of the calcarine sulcus; CCol = caudal collateral sulcus; CCol(L) = lateral branch of the caudal collateral sulcus; CCol(M) = medial branch of the caudal collateral sulcus; Fsf = fusiform gyrus; InLing = intralingual sulcus; Isth = isthmus of the cingulate sulcus; Ling = lingual gyrus; O3 = inferior occipital gyrus; OccTemp = occipitotemporal sulcus; Php = parahippocampal gyrus; PON = preoccipital notch; POS = parieto-occipital sulcus; T3 = inferior temporal gyrus

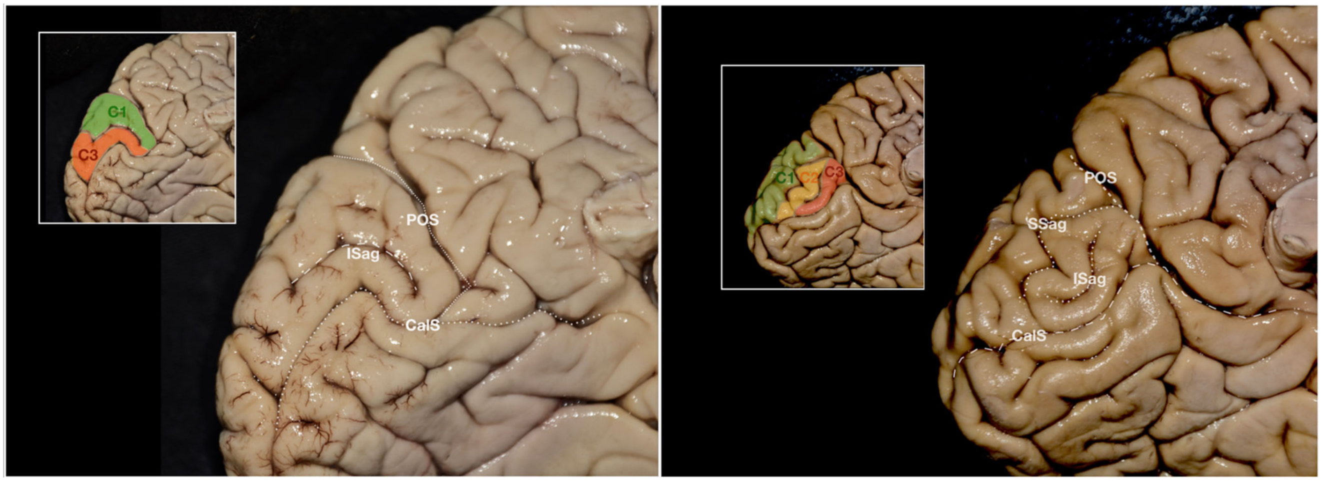

Fig. 5 Gyral patterns of the cuneus. Medial views of two left hemispheres. LEFT: The calcarine and parieto-occipital sulci demarcate the cuneus. In this specimen, only one sulcus running parallel to the calcarine, that is the inferior sagittal sulcus, can be identified. This sulcus divides the cuneus into two gyri: a superior cuneal and an inferior cuneal gyrus. INSET: The superior (C1) and inferior (C3) cuneal gyri are highlighted in green and red color, respectively. RIGHT: In this specimen two sulci, a superior sagittal and an inferior sagittal sulcus can be identified dividing the cuneus into a superior, middle, and an inferior cuneal gyri. INSET: The superior (C1), middle (C2), and inferior (C3) cuneal gyri are highlighted in green, yellow, and red color, respectively. POS = parieto-occipital sulcus; CalS = calcarine sulcus; Isag = inferior sagittal sulcus of the cuneus; SSag = superior sagittal sulcus of the cuneus; C1 = superior cuneal gyrus; C2 = middle cuneal gyrus; C3 = inferior cuneal gyrus

present in 33% (11/33) of them. We recorded up to 8 rami branching off the main trunk (continuous sulcal pattern) or the terminal branches of the posterior collateral sulcus. These branches most commonly indent the area of the lingual gyrus and are referred to as the "intralingual sulci."

Discussion

The area of the occipital lobe is characterized by a heterogeneous and highly variable superficial anatomy. Since the first focused descriptions of its sulco-gyral morphology [7, 9, 34], the nomenclature used to describe the most consistent structures of the occipital lobe has evolved through a number of studies. Nevertheless, to this day, many authors seem to use different and sometimes conflicting terms to describe the same structures. Thus, in the absence of universal anatomical definitions, a non-standardized nomenclature exists in most of the modern neuroanatomical textbooks and publications. A brief review of the contemporary literature and terminology appears in Table 2.

Our aim was therefore to explore the surface morphology of the occipital lobe and to compare our findings with the current literature, with the overarching goal to standardize a robust nomenclature for clinical and anatomical use.

Lateral occipital surface and occipital pole

The lateral occipital surface is a morphologically complex area and as such it is inconsistently described in the literature. It is bordered anteriorly by an arbitrary line that connects the lateral extension of the parieto-occipital sulcus to the preoccipital notch. Many non-consistent sulci indent the lateral occipital surface in a non-standard fashion. Most of them appear as shallow grooves running in different directions and have been described by Iaria and Petrides as the "lateral accessory occipital sulci" [16]. Three sulci travelling in a longitudinal trajectory on the lateral occipital surface, i.e., the intraoccipital sulcus, lateral occipital sulcus, and inferior occipital sulcus, are constantly observed and have been repeatedly described in the literature. However, the overlapping and inconsistent terminology used in previous studies adds anatomical perplexity and creates unnecessary confusion.

Lateral occipital sulcus

The lateral occipital sulcus is one of the most constant sulci on the lateral occipital surface. It is identified as a long sulcus running horizontally and parallel to the inferior border of the hemisphere in all studied hemispheres. Initially, Elliot Smith used the term "prelunate sulcus" to describe this structure in the early 20th century [34]. In current literature, the term "lateral occipital sulcus" is accepted, but not universally. Iaria and Petrides adopt this term, describing this structure as a horizontal sulcus located immediately anterior to the lunate sulcus [16]. Ribas and colleagues use the same name for this sulcus but additionally accept the term "Inferior Occipital Sulcus" [30]. Alves and colleagues describe this sulcus as the main horizontal sulcus of the lateral occipital surface dividing the occipital convexity into two parts but use the name "inferior occipital sulcus" [2]. Again, the term "Inferior Occipital

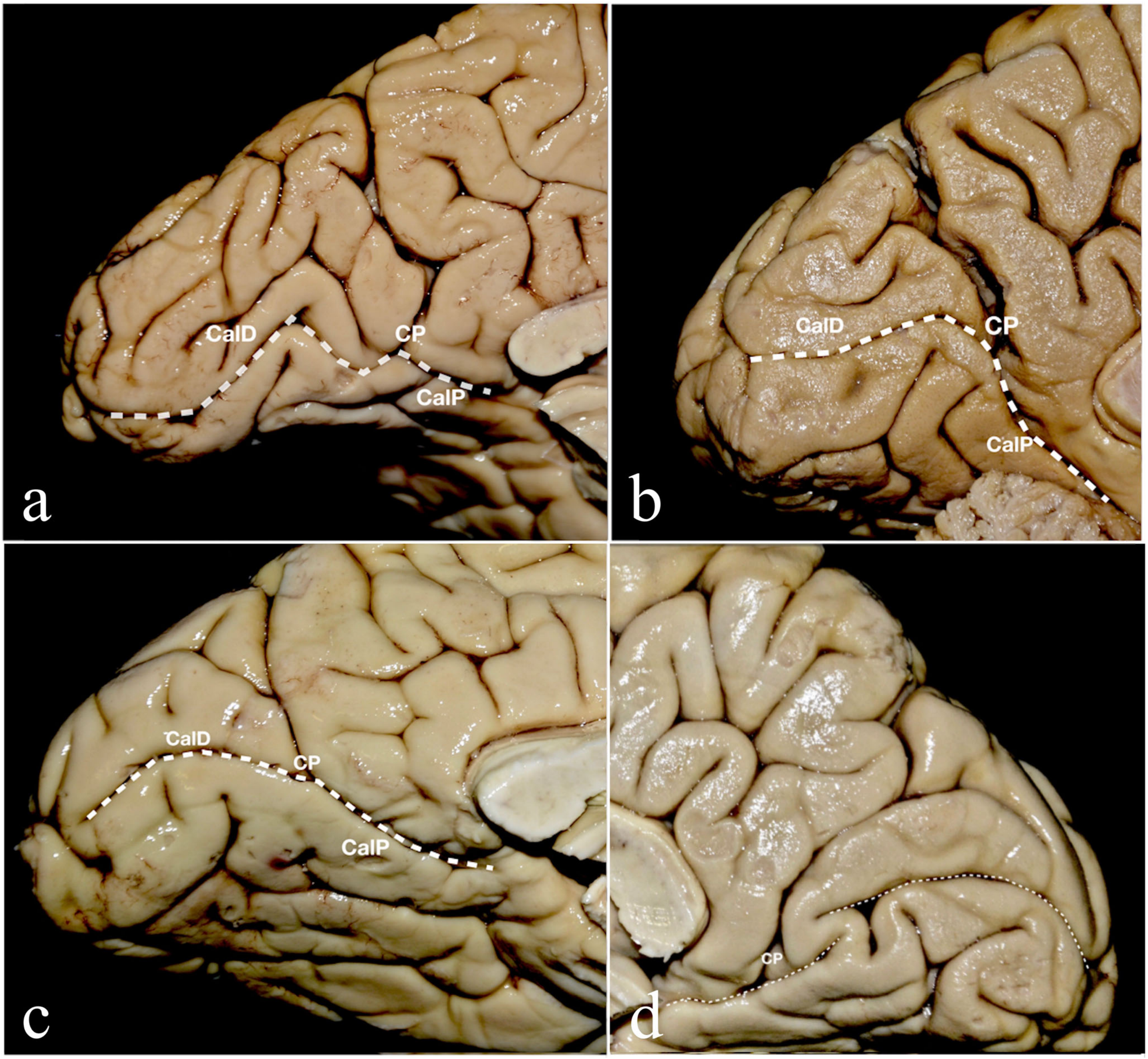

Fig. 6 Morphological patterns of the calcarine sulcus. Medial view of three (3) left and one (1) right hemisphere illustrating the different patterns of the calcarine sulcus. **a** An M-shaped calcarine sulcus is seen. This configuration is the most prevalent consisting of two curves that point superiorly. The anterior curve points towards the cuneal point. **b** Here the calcarine sulcus has a reverse V-shaped with one curve pointing to the cuneal point. **c** An S-shaped calcarine sulcus consisting of a posterior and an anterior bend is illustrated. **d** A non-continuous pattern of the calcarine sulcus is depicted. This morphology is the least prevalent. CalD = distal part of the calcarine sulcus; CalP = proximal part of the calcarine sulcus; CP = cuneal point

Sulcus" is used by Testut and Jacob and by Ono and colleagues in older studies [27, 35]. Malikovic and colleagues further introduce the complex term "Inferior Lateral Occipital sulcus" for this structure [23].

In our view, the anatomical prefix "inferior" is improper due to the presence of a prominent sulcus that is readily identified in 15% of the studied specimens and is located inferior to the lateral occipital sulcus. Therefore, the term "lateral" is more accurate than the term "inferior" with respect to the sulcal correlative topography of the occipital lobe.

Transverse occipital sulcus

In line with the current literature, we recorded the transverse occipital sulcus as fairly consistent sulcal landmark on the occipital convexity (88% of the studied hemispheres). In most of the cases, it is identified as a vertical sulcus arising from the posterior end of the intraoccipital sulcus. The term "transverse occipital sulcus" appears in the literature in a conflicting way. Ono, Ribas and Alves use this term for this specific sulcus [2, 27, 30] while Iaria and Petrides use the same term to describe

Table 2 A review of pertinent anatomical studies and summary of the relevant terminology

Review of the literature

Year	Author	Type of study	Structures described	Comparison to current study/comments
2002	Flores [11]	Cadaveric (26 hemispheres)	The authors record the presence and morphology of the following structures: -Parieto-occipital sulcus -Calcarine sulcus -Superior and inferior transverse-occipital sulcus -Preoccipital notch	The authors use a different nomenclature for the lateral occipital sulci. They use the terms superior and inferior transverse occipital sulci to describe the intraoccipital and lateral occipital sulcus, respectively
2006	Allen et al. [1]	MRI (110 individuals)	The aim of the study was the identification of the lunate sulcus and its morphology	The authors offer a classification system for the presence and morphology of the lunate sulcus
2007	Iaria and Petrides [13]	MRI (40 individuals) and cadaveric (20 hemispheres)	The authors record the presence and morphology of the following structures: -Calcarine sulcus -Inferior and superior sagittal sulci of the cuneus -Posterior collateral sulcus -Lingual sulcus -Lunate sulcus -Lateral occipital sulcus -Inferior occipital sulcus -Transverse occipital sulcus	The authors use the term transverse occipital sulcus in order to describe the intraoccipital sulcus The authors use the term accessory lateral occipital sulci to describe small non-standard sulci of the lateral surface
2010	Ribas [17]	Cadaveric	The study records the superficial anatomical landmarks of the human cerebrum. In the occipital area, the authors describe the following structures: -Calcarine sulcus -Parieto-occipital sulcus -Lingual and cuneal gyri -Superior occipital sulcus -Transverse occipital sulcus -Inferior or lateral occipital sulcus -Superior, middle, and inferior occipital gyri (O1, O2, O3) -Collateral sulcus -Temporo-occipital sulcus	The authors use the term superior occipital sulcus instead of intraoccipital sulcus
2012	Malikovic et al. [15]	Cadaveric (30 hemispheres)	The authors record the presence and morphology of the following structures: -Parieto-occipital sulcus -Calcarine sulcus -Paracalcarine sulci -Lingual sulcus -Collateral sulcus -Occipitotemporal sulcus -Transverse occipital sulcus -Superior occipital sulcus -Inferior lateral occipital sulcus -Superior lateral occipital sulcus -Inferior occipital sulcus -Anterior occipital sulcus -Lunate sulcus -Occipitopolar sulcus -Retrocalcarine sulcus	The authors use the term superior occipital sulcus instead of the term intraoccipital sulcus The authors use the term inferior lateral occipital sulcus to describe the lateral occipital sulcus The term superior lateral occipital sulcus corresponds to the medial occipital sulcus
2012	Alves et al. [2]	Cadaveric (20 hemispheres)	The authors focus on the morphology of the lateral aspect of the occipital lobe. They describe the following structures: -Intraoccipital sulcus -Transverse occipital sulcus -Lateral occipital sulcus -Lunate sulcus -Calcarine fissure -Anterior occipital sulcus -Superior, middle, and inferior occipital gyri -Superior and inferior parieto-occipital fold	The nomenclature used for the description of the occipital convexity is the same as in the current study

Table 2 (continued)

Review of the literature

Year	Author	Type of study	Structures described	Comparison to current study/comments
			-Superior and inferior temporo-occipital fold	
2014	Chau et al. [5]	Cadaveric (30 hemispheres)	The study focuses on the morphology of the basal temporo-occipital region. In the basal occipital area, the authors describe the following structures: -Caudal collateral sulcus -Intralingual sulci -Occipitotemporal sulcus	The term posterior collateral sulcus is used instead of the term caudal collateral sulcus in the current study

the intraoccipital sulcus [16]. Nonetheless, since the intraoccipital sulcus exhibits a horizontal rather than a vertical configuration, the term "transverse" seems inappropriate and adds confusion to the reader.

Intraoccipital sulcus

The intraoccipital sulcus always indents the supero-lateral aspect of the occipital convexity (100% of cases) and is, in essence, the posterior continuation of the intraparietal sulcus. In the classical studies of the early 20th century, the terms "Paraoccipital sulcus" and "Sulcus Occipitalis Primus" have been used [10, 34]. In modern literature, this structure has been interchangeably named as the "Superior Occipital Sulcus," "Paraoccipital Sulcus," or "Transverse Occipital Sulcus." Iaria and Petrides use the term "Transverse Occipital Sulcus" to describe this structure [16]. This approach may however add unnecessary perplexity and confuse the reader since the term "Transverse Occipital Sulcus" is used in the majority of the recent studies to describe a vertically oriented sulcus located at the posterior end of the intraoccipital sulcus (see comment above). Most authors prefer the term "Superior Occipital Sulcus" while Alves and colleagues advocate the term "Intraoccipital Sulcus" [2]. In our view, both these options are proper. Nevertheless, this sulcus is usually recorded as the continuation of the intraparietal sulcus and therefore the name "Intraoccipital" seems more appropriate since it better conveys the concept of cerebral anatomical integrity.

Lunate sulcus

The lunate sulcus is defined as a crescent-shaped sulcus facing the apex of the occipital lobe. It has been a topic of extended research due to the fact that it is considered homologous to the "Affenspalte," a sulcus that anatomically delineates the primary visual cortex in non-human primates. Connolly in 1950 and Allen in 2006 offered a solid description of the morphology of the lunate sulcus and its different morphological patterns [1, 6]. Allen proposed three different anatomical configurations for the lunate sulcus as opposed to the 5-tier pattern of Connolly. With regard to Allen's categorization, the "typical lunate sulcus" consists of a continuous sulcus, while the "composite lunate sulcus" is formed by the convergence of 2 or more adjacent sulci. The third category refers to the absence of an obvious lunate sulcus. In the current study, the lunate sulcus was readily identified in 66% of the specimens. This percentage is significantly higher than that of previous reports [2, 8, 16, 22]. Moreover, we recorded the lunate sulcus to merge with the transverse or the lateral occipital sulcus in less than 25% of cases. The term used to describe this sulcus remains constant and consistent throughout the literature and therefore no misinterpretations exist with regard to the anatomical nomenclature.

Anterior occipital sulcus

The anterior occipital sulcus is defined as a vertical sulcus running parallel to the arbitrary line used to demarcate the anterior border of the occipital lobe. It has been described in previous studies [2, 8, 23, 41]. Interestingly, the frequency of this sulcus is highly variable in the literature. Alves and colleagues recorded the anterior occipital sulcus in only 10% of the studied hemispheres [2] while Malikovich et al. identified this sulcus in all specimens [23]. In our study, the anterior occipital sulcus was evident in 24% of the hemispheres, showing a predominance for the right side. The nomenclature used is consistent throughout the relevant literature.

Retrocalcarine and occipitopolar sulci

The retrocalcarine and occipitopolar sulci are two crescent-shaped, vertical, short and non-constant sulci that have been scarcely described in the literature [16, 23]. In the current study, we have recorded these sulci to appear concurrently in less than 10% of the cases. They were found to lie anterior to the apex of the occipital pole and when both present, they delineate the gyrus descendens.

Marginal occipital sulcus

In the current study we identified, documented, and described for the first time in the literature a straight, "H," or "T"-shaped sulcus, running at the level of the superior margin of the occipital lobe or slightly lateral to it, either separating the superior occipital gyrus from the cuneus or indenting the superior occipital gyrus (Fig. 7). Due to the topography of the sulcus, which lies close to the superior margin of the occipital convexity and between its medial and lateral aspects, we have coined the term "marginal occipital sulcus" since it reflects its main anatomical characteristic.

Medial and basal surface of the occipital lobe

Calcarine sulcus

The calcarine sulcus originates at the retrosplenial area and travels in a postero-superior trajectory towards the area of the occipital pole. It meets with the inferior segment of the parieto-occipital sulcus in a point known as the cuneal point. This point divides the calcarine sulcus into two parts that have been described in the literature with variable terms. Early publications describe the part of the calcarine sulcus anterior to the cuneal point as the "sulcus calcarinus proprius" [34] or the "trunk of the parieto-occipital and calcarine sulci" [10]. In current literature, the terms "proximal calcarine sulcus" [30] or "anterior calcarine sulcus" [16] are more common. The part of the calcarine sulcus extending posterior the cuneal point is known as the "distal" [2] or "posterior calcarine sulcus" [16]. In earlier studies, the name "retrocalcarine sulcus" [34] is also encountered, but currently this term stands for the bifid termination of the calcarine sulcus.

Malikovich and colleagues propose a 3-part segmentation of the calcarine sulcus: an anterior part (anterior to the CP), a middle part, and a posterior part that corresponds to the termination of the sulcus in the area of the occipital pole and is known as the retrocalcarine sulcus. The same authors recorded the retrocalcarine sulcus in 79.9% of the specimens and found it running on the medial aspect of the hemisphere in the majority of cases [23]. On the contrary, we identified the retrocalcarine sulcus in 12% of cases, most often seen to reach the apex of the occipital pole. In our view, the classical segmentation using the terminology "proximal" and "distal calcarine sulcus" is more appropriate and applicable in the majority of cases. With regard to the morphology of the calcarine sulcus, we have observed an M-shaped (two-apex) pattern in 70% of specimens. Interestingly, in our cohort, the anterior apex was always seen to point towards the cuneal point. On the contrary, Malikovich and colleagues recorded the single apex pattern to be the most frequent (60% of cases) [23].

Parieto-occipital sulcus

The parieto-occipital sulcus represents a consistent landmark on the medial cerebral aspect. Along with the distal part of the calcarine sulcus, it demarcates the cuneal lobule from the precuneal lobule. In our study, the parieto-occipital sulcus appears on the superior margin of the hemisphere, continuing as the external perpendicular fissure, in the majority of the cases. In line with the literature, a "Y-shaped" morphology was most frequently evident. The terminology regarding this sulcus is widely accepted [14].

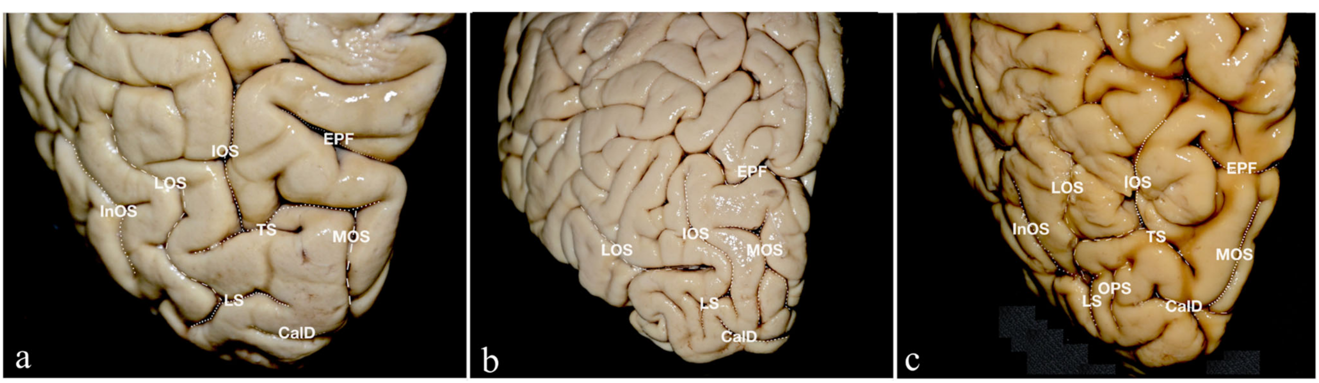

Fig. 7 Morphological patterns of the marginal occipital sulcus. Postero-superior views of three (3) left hemispheres. **a** Typical superficial anatomy of the occipital convexity. The intraoccipital, lateral occipital, and inferior occipital sulci can be identified. The intraoccipital sulcus intersects with the transverse occipital sulcus while the lateral occipital sulcus meets the lunate sulcus. A T-shaped marginal occipital sulcus is documented. A small sulcus connecting the marginal occipital and the transverse occipital sulcus is also depicted. **b** In this specimen, the intraoccipital sulcus intersects with the lunate sulcus while the transverse occipital sulcus is absent. Here the marginal occipital sulcus has an "H" shape. **c** In this hemisphere, the marginal occipital sulcus takes a straight trajectory and meets the distal part of the calcarine sulcus. A prominent occipitopolar sulcus is also apparent. CalD = distal part of the calcarine sulcus; EPF = external perpendicular fissure; InOS = inferior occipital sulcus; IOS = intraoccipital sulcus; LOS = lateral occipital sulcus; LS = lunate sulcus; MOS = marginal occipital sulcus; OPS = occipitopolar sulcus; TS = transverse occipital sulcus

Superior and inferior sagittal sulci

The cuneus is frequently indented by a number of small sulci that may follow different trajectories. These sulci usually branch off the calcarine or the parieto-occipital sulci but may also stem individually. In the literature, the most typical morphological sulcal pattern of the cuneus comprises two sulci, namely the inferior sagittal sulcus and superior sagittal sulcus [10, 16]. In our view, the term "paracalcarine sulci" used by some authors [23] is not appropriate since these sulci do not always lie adjacent nor arise from the calcarine sulcus.

We identified two sulci in this area. One of them was present in 24% of cases and was recorded to travel either adjacent to the calcarine sulcus or to branch from its distal part. For classification purposes, we prefer the term "inferior sagittal sulcus" as it reflects more accurately the sulcal trajectory and topography. The second sulcus was recorded in 67% specimens and was encountered adjacent and parallel to the parieto-occipital sulcus. In some cases, this sulcus was also seen to branch off the parieto-occipital sulcus. Again, in our view, the term "superior sagittal sulcus" is more characteristic and suitable for this structure.

Intralingual sulci

Our results concerning the sulcal morphology of the lingual gyrus are in agreement with the literature. In 90% of cases, we recorded 1 or 2 sulci indenting this area and dividing it into 2 or 3 parts. The terms "lingual" [10, 23] or "intralingual" sulci [5, 27] have been widely accepted in modern studies. In our view, the prefix "intralingual" is more precise since it reflects the exact location of these sulci.

Collateral and temporo-occipital sulci

The basal temporo-occipital surface is traversed by two longitudinal sulci, i.e., the posterior collateral sulcus and the posterior temporo-occipital sulcus. Chau and colleagues divide the collateral sulcus into a rhinal segment, a proper segment, and a caudal (or occipital) segment, with the latter originating at the level of the temporo-occipital line [5]. The same author recorded a bifurcation pattern of the caudal collateral sulcus in 87% of the studied hemispheres. In the current study, this pattern was identified in 33% of cases. Our findings with regard to the anatomy of the posterior temporo-occipital sulcus are generally in line with the literature. The frequency of the interrupted pattern of the temporo-occipital sulcus was in agreement with the study by Chau and colleagues (30 and 33%, respectively). In our cohort, the percentage of the temporo-occipital sulcus recorded to intersect with the collateral was lower than the percentage published by the same authors (24 and 40%, respectively). The terminology used for this sulcus is consistent in modern literature.

Surgical utility of cerebral sulci

The microsurgical concept of using cisterns, fissures, and cerebral sulci as operative corridors to access deep-seated lesions has been mainly proposed and popularized by the seminal anatomical and clinical work of Professor Yasargil [38–40]. In this context, during the so-called transsulcal approach, the surgeon has to open the arachnoid covering of the sulcus and carefully advance the intraoperative dissection up until the sulcal fundus is reached, while preserving the pial planes that invest the vessels that live inside the sulcus. Given the fact that most of the cerebral sulci point towards the respective part of the ventricular system [15], this surgical maneuver offers a safe, straight, and effective operative trajectory for managing para and intraventricular lesions. When compared to the standard transcortical approach, the transsulcal corridor minimizes normal brain transgression and provides a shorter working angle to attack deep-seated lesions [13, 17–21, 24–26, 28]. However, the clinical applicability, feasibility, and effectiveness of the transsulcal operative variant depends heavily on the unique anatomical characteristics of the sulcus that is intended to be used. Hence, the sulcal length, depth, trajectory, and its surface morphology have to be meticulously studied on preoperative imaging [13, 17, 19, 20, 24, 26]. A complex, non-continuous, and shallow sulcus is a potential contraindication for performing the approach. In our previous anatomo-imaging studies [19, 20] that refer to this topic, we have shown that a straight, uninterrupted sulcal segment of 2, 5–3 cm has to be dissected in real clinical settings in order to provide adequate access and optimal surgical maneuverability for intraventricular lesions. This length can be reduced down to 1, 5–2 cm with the use of small tubular retractors that can be gradually advanced under intraoperative navigation into the ventricular compartment [11]. In addition, special attention has to be placed to the presence of gyri that reside within the sulcus—the so-called intrasulcal gyri—which, when prominent and voluminous, can convert a transsulcal approach to a mixed transsulcal-transcortical as the surgeon tries to reach the sulcal fundus [19, 20].

Although using normal cerebral corridors like the sulci for approaching and resecting deep-seated lesions is a time consuming process, it is nonetheless a very delicate and elegant endeavor that, under specific circumstances, respects cortical anatomy and minimizes normal parenchymal injury [15, 28, 38–40]. Accurate knowledge of cortical and subcortical functional anatomy, meticulous preoperative planning, and advanced microneurosurgical dissection skills affect surgical precision and ultimately patient's outcome.

Conclusion

The superficial anatomy of the occipital lobe has been implicated in a number of contemporary and classical studies. Nevertheless, a vague understanding of the sulco-gyral morphology and topography of this region remains and is conveyed mainly as a lack of solid anatomical definitions and as an absence of a universal nomenclature. By combining a review of the relevant current literature with a meticulous investigation of the surface topography and morphology of the occipital sulci and gyri in 33 formalin-fixed cerebral hemispheres, we attempt to offer a more sophisticated anatomical perspective and propose a universal taxonomy of the occipital cortical anatomy for clinical and anatomical use. In addition, we identify, record, and describe for the first time in the literature a sulcus that runs on the supero-lateral aspect of the occipital surface, which we name the marginal occipital sulcus after its specific topography.

Authors' contributions Author contributions to the study and manuscript preparation include the following. Conception and design: Koutsarnakis. Acquisition of data: Drosos, Koutsarnakis, Komaitis. Analysis and interpretation of data: Komaitis, Koutsarnakis, Drosos, Kalyvas, Skandalakis. Drafting the article: Komaitis, Koutsarnakis, Kalyvas. Critically revising the article: Koutsarnakis, Kalyvas, Komaitis, Kalamatianos, Liakos, Stranjalis. Reviewed submitted version of manuscript: All authors. Administrative technical, material support: Stranjalis. Study supervision: Koutsarnakis.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest regarding the materials or methods used in the current study or the findings specified in this paper.

Ethical approval This is a cadaveric study not involving human participants and/or animals and therefore does require authorization of ethical committee (ethical approval).

Informed consent This is a cadaveric study not involving human participants or patient information and therefore does not require ethical approval or informed consent.

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