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MAPPING OF THE EXTERIOR CEREBRAL ARCHITECTURE IN DONKEY (*EQUUS ASINUS*)

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ABSTRACT

Morphological identification of the cerebral cortex is crucial for the recognition and mapping of various brain functions. The objective of this study was to grossly describe the sulci and gyri in the exterior cerebral cortex of the donkey's brain. To achieve this study, we used fifteen cadaveric heads of adult healthy donkeys, free from neurological disorders. These heads were preserved in 10% formalin for two weeks, and then they were gently dissected to extract the brain. The cerebral cortex of these specimens was precisely inspected to identify the morphology, location, and extension pattern of each gyrus and sulcus. The identified gyri and sulci were briefly described in a color-coded map representing the exterior topography of the cerebral cortex. In addition, the measurements of each gyrus and sulcus on the right and left sides of the cerebral cortex were recorded. The findings in this study revealed extensive and massive gyral and sulcal formation of the cerebral cortex in the donkey. Moreover, the identified gyri and sulci were compared to the previously described nomenclatures, which showed great similarity to those in horses, with some variability, especially the extension of the sulci and pattern of gyral formation. The statistical analysis revealed relatively variable measurements of the gyri and sulci between the right and left sides of the cerebral cortex, with no significant difference between them ($P>0.05$). The colored map of the cerebral cortex obtained in this study could help as an index reference for further neurological studies in donkeys.

Keywords: Cerebral architecture, Donkey, Gyri, Mapping, Sulci.

INTRODUCTION

The estimated donkey population is supposed to be about 43 million, with around 95% of them found in developing countries where they are used in load-carrying activities, transport, agriculture, and various industries (Leeb *et al.,* 2003; Pritchard *et al.,* 2005). In Egypt, donkeys are important working animals, especially in agricultural communities (Farhat *et al.,* 2020; Aboutaleb *et al.,* 2022). Furthermore, the donkeys' cadavers are commonly used as models of ungulate mammals instead of horses in veterinary anatomy education due to their wide availability, low cost, and smaller size (Abdallah *et al.,* 2020**)**. Even though the socio-economic importance of the donkey

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is recognized, there is limited knowledge of the neuroanatomy in this species, particularly the exterior cerebral architecture.

The brain is a vital part of the central nervous system and is responsible for coordinating crucial life functions (Cain *et al.,* 2006). The exterior surface of the cerebral cortex showed several complex convolutions, called gyri, and grooves, called sulci. This complex arrangement of the cerebral cortex is involved in many vital functions, including sensory, memory, consciousness, information processing, and motor functions (Gado *et al.,* 1979; Ribas, 2010). Organization and identification of cortical architecture could help in understanding these crucial functions. Several previous neuroanatomical studies provided a detailed view of the exterior cerebral gyri and sulci in camel (Kanan, 1973; Xie *et al.,* 2006; Al Aiyan *et al.,* 2024a) and canine (Johnson *et al.,* 2020; Al Aiyan *et al.,* 2024b). However, the previous normal neuroanatomical studies in horses (Cozzi et al., 2014; Stuckenschneider *et al.,* 2014; Schmidt *et al.,* 2019) and donkey (Hifny *et al.,* 1985; Oto and Haziroglu, 2009; Abdel Maksoud *et al.,* 2021) presented a limited overview and unclear graphical representations of the gyri and sulci in these species. Accordingly, subsequent studies are highly needed to improve our understanding of the cortical architecture, especially in donkeys. The purpose of the current work was to provide a comprehensive morphological atlas of the cerebral gyri and sulci to be a standard reference for further neuroanatomical studies in the donkey.

MATERIALS AND METHODS

After being approved by the ethical committee, the current study was achieved to dissect 15 donkey heads. These heads were collected from Beni-Suef Zoo, Beni-Suef Province, Egypt, after slaughtering of 15 healthy donkeys of both sexes (10 males and 5 non-pregnant females), with an average age of 12.57 ± 0.813 years and an average weight of 176.6 ± 4.76 kg. The heads of the slaughtered animals were cut at the level of the atlantoaxial joint, cleansed with tap water, and prepared for dissection. The common carotid arteries of these specimens were thoroughly rinsed with a normal saline solution before being injected with a 10% formalin solution. Following this, the specimens were preserved in a 10% formalin solution for a period of two weeks. The skulls of the preserved specimens were carefully dissected using anatomical instruments for the extraction of the brains. The meninges around the extracted brains were gently removed to expose the cerebral hemispheres. The gyri and sulci in the exterior surface and sagittal section of each brain were precisely inspected, identified, and photographed. The captured images were labelled and color-coded using Photoshop 2020 (version 21.1.1). The terminology of the gyri and sulci in this study was based on the description of Nomina Anatomica Veterinaria, published articles in donkeys (Hifny *et al.,* 1985), and related anatomy textbooks (Dellman and McCure, 1975; Constantinescu and Schaller, 2018).

Statistics

The measurements of each gyrus and sulcus on the right and left sides of the cerebral cortex in the investigated specimens (*n*=15) were recorded. The mean value and standard deviations (SD) of the length and width of the gyri and the length and depth of the sulci were measured in cm. A t-test was used to measure the significant difference between the parameters of the gyri and sulci on the right and left sides of the cerebral cortex. All statistics in the current study were conducted using SPSS Statistics (SPSS Statistics IBM, 2020 Aromonk, New York).

Ethical approval
The current work was a cadaveric study approved by the Institutional Animal Care and Use Committee of Beni-Suef University, Egypt (BSU-IACUC, Permit Number: 024-077). All the experiments conducted in this study were conducted according to the relevant guidelines and regulations.

RESULTS

The largest part of the brain, the cerebrum, includes the two cerebral hemispheres and their commissural fibers. These hemispheres were separated dorsally by the deep longitudinal fissure, and caudally, they were separated from the cerebellum by the transverse fissure. Each hemisphere had lateral, dorsal, medial, and basal surfaces. The dorsal, lateral, and medial surfaces of each hemisphere (cerebral cortex) showed numerous convolutions, the gyri, and depressions, the sulci. The precise location, relations, and extension pattern of each gyrus and sulcus were fully described in this study in order to establish a color-coded gyrencephalic brain in the donkey.

Cerebral sulci
The cerebral cortex in the donkey exhibited an extensive network of grooves that demarcated the cerebral gyri. These sulci were extensively variable in depth, ramification, and extension, especially in the dorsolateral aspect of each hemisphere, indicating bilateral asymmetry of the cerebral cortex. Furthermore, on the same side of the cerebral hemisphere, the sulci appeared with variable extensions: longer and slightly convoluted in the dorsal aspect, short and straight in the rostral part, and shorter and highly convoluted in the caudoventral part (Figs. 1, 2). While the cerebral sulci exhibited more regular extension on the medial aspect of the cerebral hemisphere (Fig. 3). Moreover, the length and depth of each sulcus were reported in Table (1), showing relatively variable parameters between the right and left sides of the cerebral cortex with no significant difference between them ($P>0.05$).

The cerebral cortex was separated from the underlying rhinencephalon by the lateral and medial rhinal sulci. The lateral one was the most ventrolateral sulcus of the cerebral hemisphere and had two parts, rostral and caudal. The rostral part of the lateral rhinal sulcus separating between the prorean gyrus dorsally and rhinencephalon ventrally and extends caudally to merge with the caudal one ventral to the insular gyri at the level of the sylvian fissure. While the caudal part of the lateral rhinal sulcus extended caudally, dorsal to the pyriform lobe and ventral to the occipital gyrus to terminate in the transverse fissure (Figs. 1, 2). The medial rhinal sulcus was found on the medial aspect of the cerebral hemisphere between the rhinencephalon and the medial part of the prorean gyrus and extended caudally till the level of the subcallosal gyrus (Fig. 4).

The Sylvian fissure was the deepest fissure on the lateral surface of the cerebral hemisphere in the donkey brain. This fissure arose just dorsal to the pyriform lobe, communicating freely with the caudal part of the lateral rhinal sulcus. Moreover, this fissure extended dorsal to the insular gyri with a narrow width and linear pattern forming three branches; the rostral one extended between the diagonal and rostral ectosylvian gyri, while the middle and caudal branches insinuated between the folds of the rostral sylvian gyrus (Figs. 1, 2). It was observed that this fissure represented the approximate middle point of the lateral cerebral hemisphere, defining the outlines of the frontal, temporal, and parietal lobes.

The presylvian sulcus was found on the lateral surface of the cerebral hemisphere, originating from dorsal to the rostral limb of the insular gyri. This sulcus extended rostrodorsally between the diagonal and prorean gyri to communicate with the cruciate sulcus (Figs. 1-3).

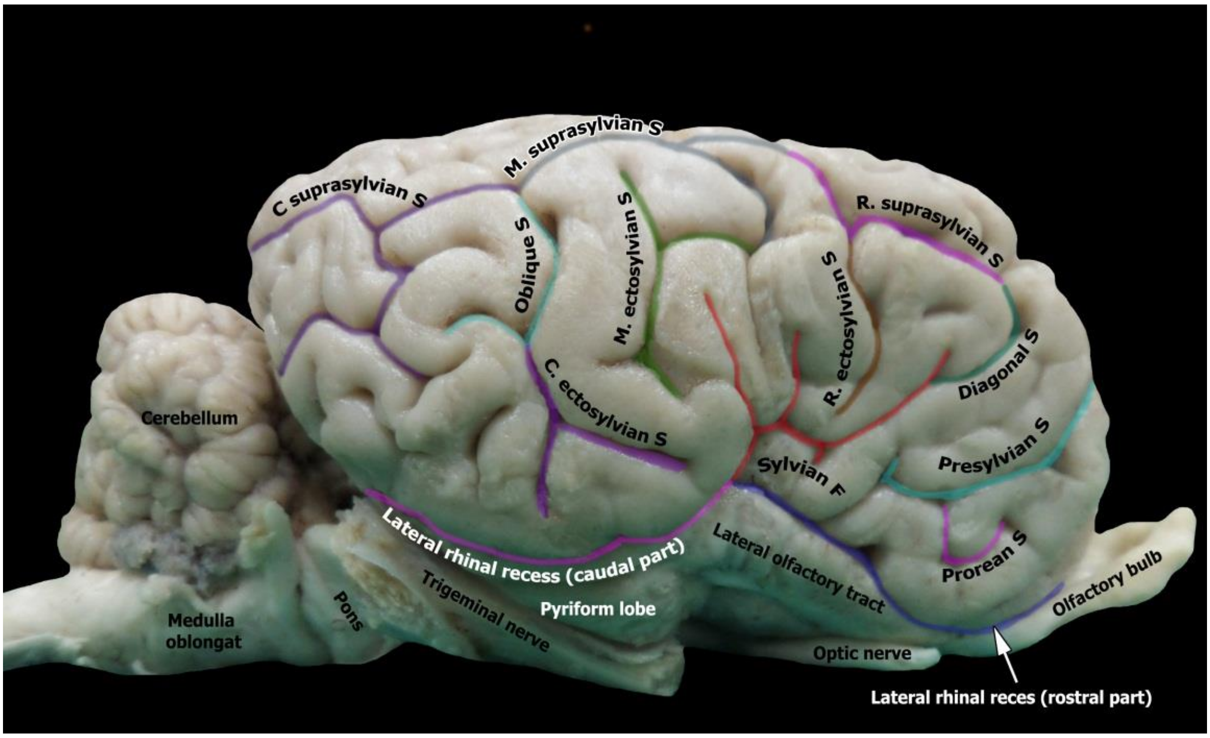

Figure 1: Lateral view of the right cerebral hemisphere of donkey, the colored lines showed the sulci of the lateral surface.

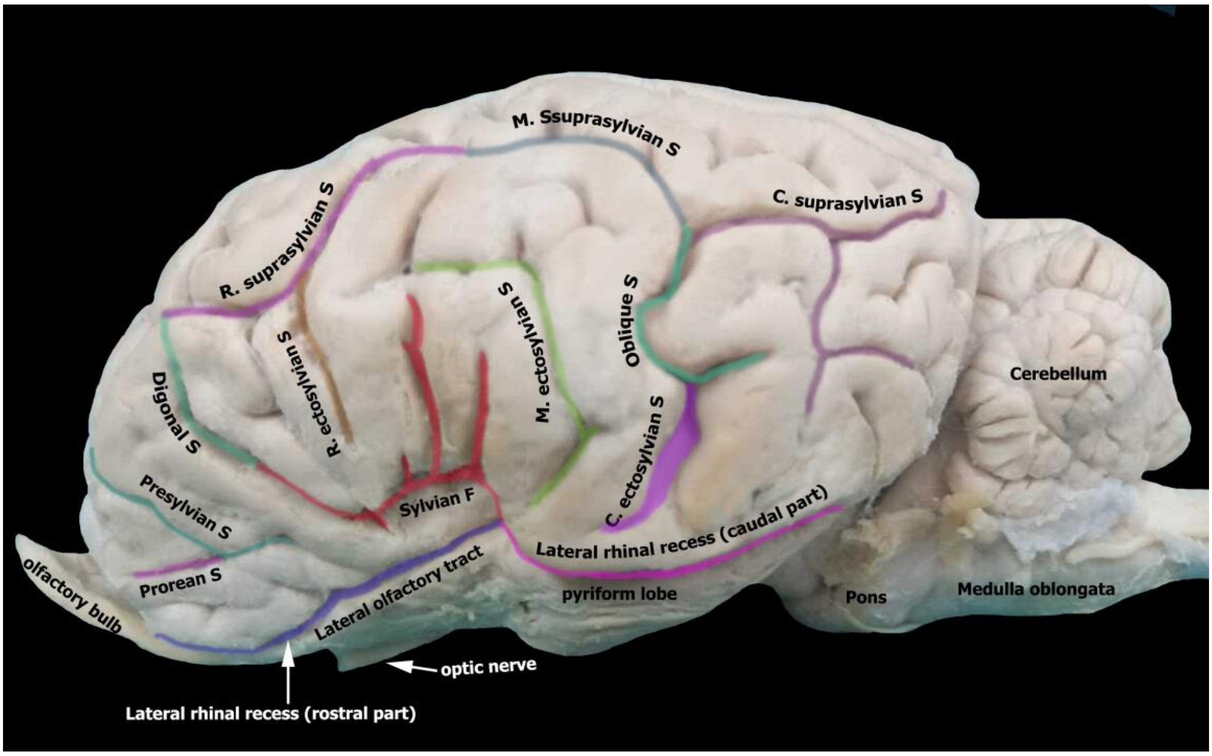

Figure 2: Lateral view of the left cerebral hemisphere of donkey, the colored lines showed the sulci of the lateral surface.

Table 1: Mean ± standard deviations of the length and depth of the sulci on the right and left sides of the cerebral cortex in 15 adult donkeys.

	Length (cm)		**Depth (cm)**	
	On right side	**On left side**	**On right side**	**On left side**
Lateral rhinal sulcus (rostral part)	4.88 ± 0.22	4.80 ± 0.22	0.31 ± 0.11	0.32 ± 0.05
Lateral rhinal sulcus (caudal part)	5.06 ± 0.33	5.07 ± 0.33	0.20 ± 0.06	0.22 ± 0.12
Medial rhinal sulcus	2.45 ± 0.13	2.62 ± 0.15	0.98 ± 0.07	0.97 ± 0.19
Sylvian fissure, rostral branch	2.03 ± 0.18	1.92 ± 0.18	1.08 ± 0.11	1.12 ± 0.09
Sylvian fissure, middle branch	1.21 ± 0.22	1.42 ± 0.22	1.46 ± 0.10	1.57 ± 0.22
Sylvian fissure, caudal branch	2.06 ± 0.16	1.82 ± 0.18	1.21 ± 0.07	1.17 ± 0.15
Presylvian sulcus	3.03 ± 0.16	2.90 ± 0.16	0.48 ± 0.07	0.57 ± 0.09
Prorean sulcus	1.43 ± 0.12	1.47 ± 0.20	0.21 ± 0.07	0.22 ± 0.12
Diagonal sulcus	1.72 ± 0.17	1.62 ± 0.18	0.63 ± 0.12	0.70 ± 0.11
Rostral ectosylvian sulcus	2.11 ± 0.17	2.00 ± 0.22	0.30 ± 0.12	0.30 ± 0.08
Middle ectosylvian sulcus	2.86 ± 0.16	2.87 ± 0.33	0.35 ± 0.10	0.32 ± 0.05
Caudal ectosylvian sulcus	2.00 ± 0.10	1.85 ± 0.10	0.66 ± 0.12	0.70 ± 0.14
Rostral suprasylvian sulcus	3.18 ± 0.25	3.35 ± 0.25	0.81 ± 0.11	0.82 ± 0.05
Middle suprasylvian sulcus	3.93 ± 0.16	4.05 ± 0.26	0.61 ± 0.07	0.57 ± 0.15
Caudal suprasylvian sulcus	5.88 ± 0.18	5.75 ± 0.22	0.82 ± 0.10	0.61 ± 0.12
Oblique sulcus	2.45 ± 0.16	2.37 ± 0.11	0.81 ± 0.11	0.95 ± 0.12
Marginal sulcus	6.08 ± 0.18	6.12 ± 0.18	0.28 ± 0.07	0.25 ± 0.05
Endomarginal sulcus	4.68 ± 0.25	4.77 ± 0.40	0.26 ± 0.13	0.25 ± 0.17
Rostral ectomarginal sulcus	3.11 ± 0.21	3.20 ± 0.20	0.78 ± 0.14	0.70 ± 0.08
Caudal ectomarginal sulcus	5.38 ± 0.25	5.35 ± 0.40	0.73 ± 0.15	0.70 ± 0.25
Ansate sulcus	4.03 ± 0.24	3.92 ± 0.23	0.76 ± 0.08	0.80 ± 0.08
Cruciate sulcus	3.55 ± 0.13	3.77 ± 0.17	0.38 ± 0.07	0.40 ± 0.08
Splenial sulcus	8.63 ± 0.20	8.72 ± 0.32	0.67 ± 0.15	0.58 ± 0.07
Genual sulcus	1.38 ± 0.11	1.25 ± 0.12	0.20 ± 0.08	0.20 ± 0.08
Calarine sulcus	1.81 ± 0.19	1.75 ± 0.20	0.55 ± 0.17	0.45 ± 0.10
Corpus callosal sulcus	6.93 ± 0.16	7.00 ± 0.16	0.23 ± 0.16	0.32 ± 0.15
Suprasplenial sulcus	1.88 ± 0.14	1.95 ± 0.19	0.20 ± 0.08	0.17 ± 0.12
Internal rostral sulcus	3.00 ± 0.14	3.20 ± 0.18	0.25 ± 0.10	0.20 ± 0.08

The prorean sulcus was a small and shallow groove that delineated the dorsal border of the prorean gyrus, and it continued dorsally with the presylvian sulcus (Figs. 1, 2).

The diagonal sulcus was observed on the lateral surface of the cerebral hemisphere, arising from the rostral branch of the sylvian fissure dorsal to the insular gyri. In addition, this sulcus extended rostro-dorsally between the rostral ectosylvian and diagonal gyri to merge with the rostral suprasylvian sulcus (Figs. 1, 2).

The ectosylvian sulcus was located ventral to the suprasylvian sulcus, forming an interrupted arch around the sylvian gyri and sylvian fissure. This groove was subdivided into three sections with different orientations: rostral, middle, and caudal. The rostral ectosylvian sulcus originated from the rostral suprasylvian sulcus and passed ventrally in an oblique manner to separate the rostral ectosylvian and rostral sylvian gyri. The middle ectosylvian sulcus was a slightly oblique groove separating the rostral sylvian and rostral oblique gyri. The caudal ectosylvian sulcus appeared deeper; it was found between the oblique gyri and the caudal sylvian gyrus. On the right side of the cerebral cortex, the distal part of the later sulcus appeared bifurcated (Fig. 1), while on the left side it appeared straight (Fig. 2).

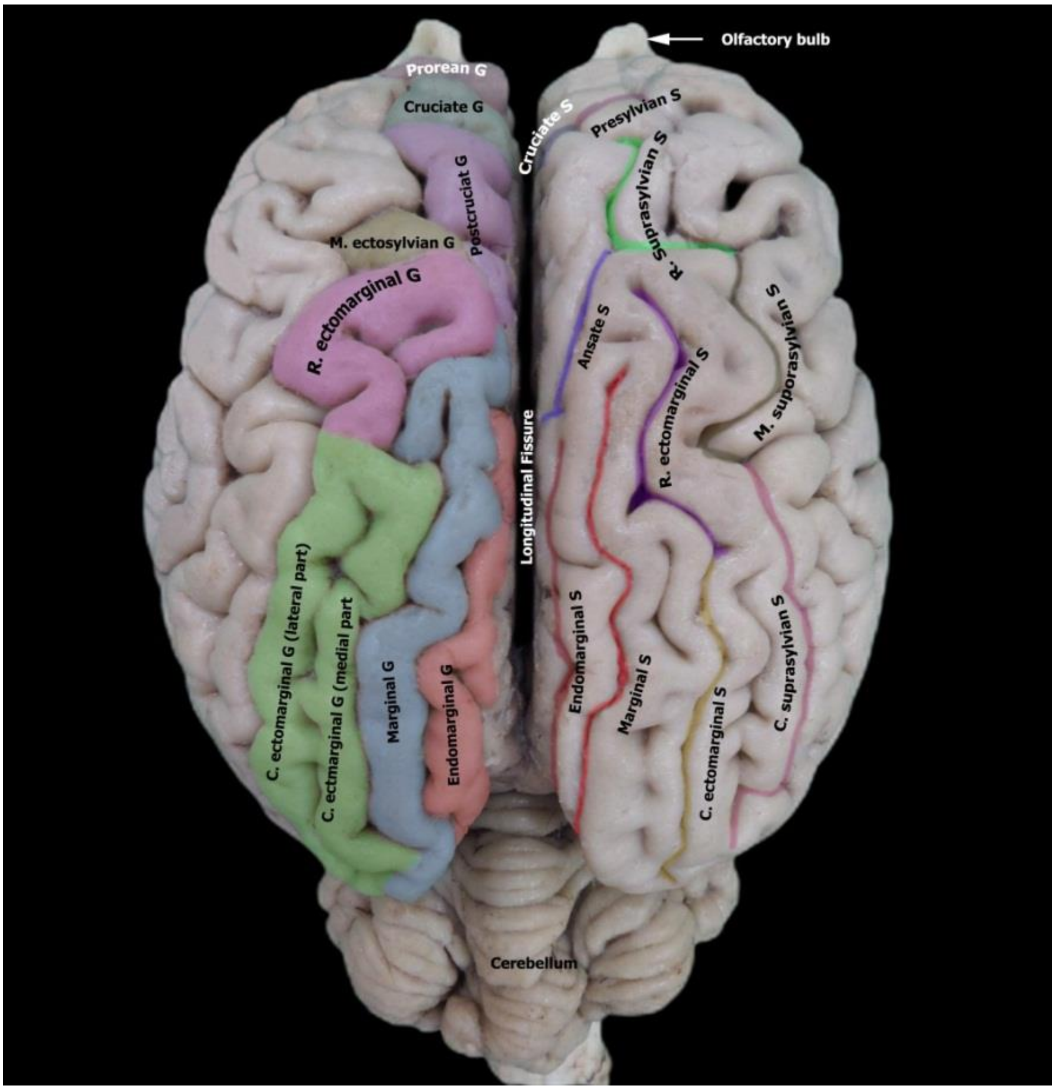

Figure 3: Dorsal view of the cerebral hemispheres of donkey, the colored lines showed the sulci in the right cerebral hemisphere and the colored illustrations showed the gyri of the left one

The suprasylvian sulcus was a long groove extending along the dorsolateral aspect of the cerebral hemisphere and roughly divided the cerebral hemisphere into lateral and dorsal sections. This groove was subdivided into three parts: rostral, middle, and caudal. The rostral suprasylvian sulcus ran caudodorsally between the rostral ectosylvian and postcruciate gyri till it anastomosed with the middle one dorsal to the middle ectosylvian gyrus. The middle suprasylvian sulcus continued caudally in parallel to the rostral ectomarginal sulcus to continue as the caudal suprasylvian sulcus. The latter sulcus continued caudally until the level of the transverse fissure separating between the marginal gyri dorsally and the sylvian gyri ventrolaterally. Moreover, the suprasylvian sulcus extended ventrally between the caudal ectosylvian and occipital gyri to enclose the occipital gyrus and delineate the dorsal border of the caudal composite gyrus (Figs. 1-3).

The oblique sulcus arose from the caudal suprasylvian sulcus, and it extended ventrally between the oblique and caudal ectosylvian gyri to join the caudal ectosylvian sulcus (Figs. 1, 2).

The marginal sulcus was found on the dorsal aspect of the cerebral hemisphere, beginning caudal to the ansate sulcus and run caudally parallel to the longitudinal fissure to separate between the marginal and ectomarginal gyri till reaching the occipital lobe (Fig. 3).

The endomarginal sulcus was a shallow and short sulcus located within the longitudinal fissure in the most caudomedial part of the cerebral hemisphere and flanked by the marginal sulcus. Furthermore, this sulcus outlined the dorsal border of the endomarginal gyrus, separating it from the marginal gyrus (Figs. 3, 4).

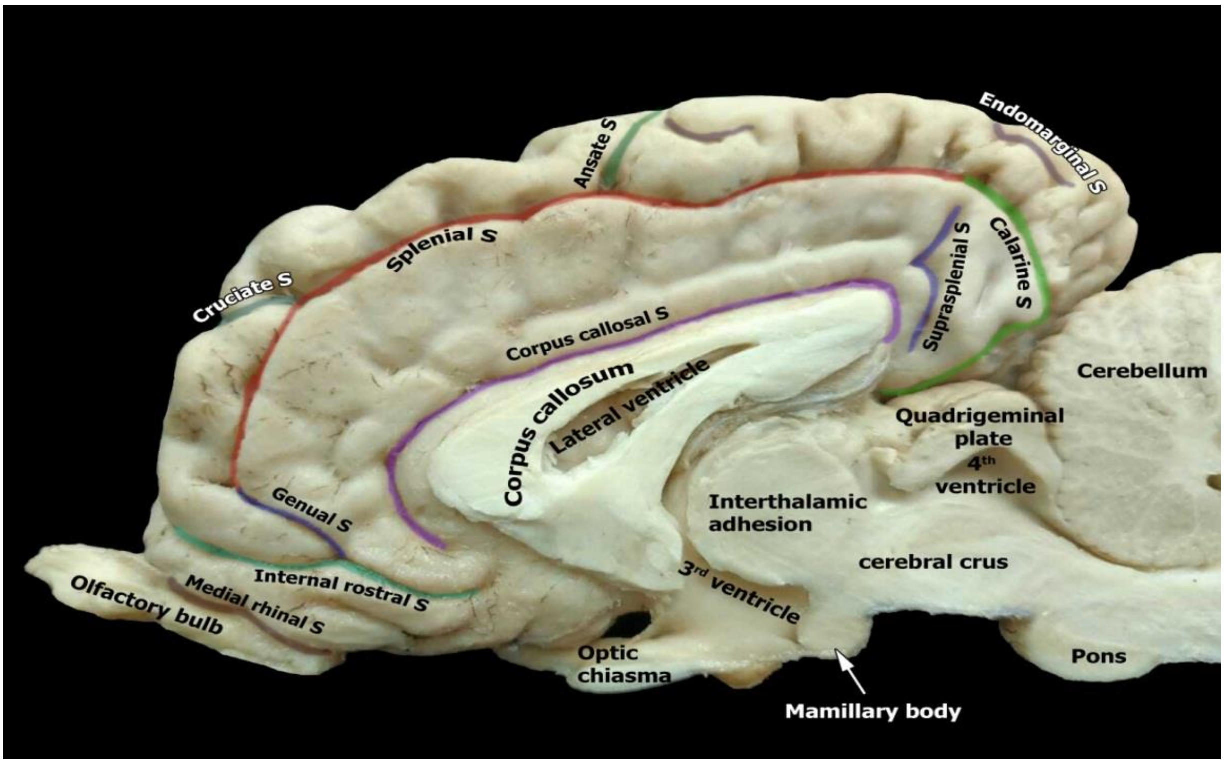

Figure 4: Medial view of the right cerebral hemisphere of donkey, the colored lines showed the sulci of the medial surface.

The ectomarginal sulcus was positioned ventrolateral to the marginal sulcus, and it possessed two segments: rostral and caudal. The rostral ectomarginal sulcus began caudal to the rostral ectomarginal gyrus and passed caudally between the marginal and ectomarginal gyri to terminate in the caudal one. The caudal ectomarginal sulcus continued caudally dorsal to the suprasylvian sulcus until the occipital lobe (Fig. 3).

The ansate sulcus was a short sulcus located nearly at the midpoint of the dorsal aspect of the cerebral hemisphere. This sulcus arose from the splenial sulcus and ran dorsally and laterally to join the rostral suprasylvian sulcus (Figs. 3, 4).

The cruciate sulcus was a short sulcus located on the dorsomedial aspect of the cerebral hemisphere between the cruciate and postcruciate gyri (Figs. 3, 4).

The splenial sulcus was the deepest and longest sulcus on the medial aspect of the cerebral hemisphere. This sulcus outlined the dorsal border of the cingulate gyrus, and it extended rostroventrally between the cingulate and genual gyri as genual sulcus and caudodorsally between the cingulate and endomarginal gyri as calarine sulcus (Fig. 4).

The corpus callosal sulcus separates the cingulate and supracallosal gyri on the medial aspect of the cerebral hemisphere (Fig. 4).

The suprasplenial sulcus was a short sulcus bordering the rostral aspect of the splenial gyrus, demarcating it from the cingulate gyrus (Fig. 4).

The internal rostral sulcus was a deep groove on the medial aspect of the cerebral hemisphere located between the genual and cingulate gyri dorsally and the prorean gyrus ventrally (Fig. 4).

Cerebral gyri

The cerebral gyri of the donkey's brain were briefly described and identified in this study, providing a thorough view of their convolutions, extensions, and relations. The length and width of each gyrus were recorded in Table (2), showing relatively variable measurements between the right and left sides of the cerebral cortex with no significant difference between them (P>0.05).

The prorean gyrus was the most rostroventral gyrus of the cerebral hemisphere and was separated from the rhinencephalon by the medial and lateral rhinal sulci. In addition, this gyrus was outlined laterally by the prorean sulcus and medially by the internal rostral sulcus (Figs. 5, 6).

The precruciate gyrus was located rostroventral to the cruciate sulcus and continued ventromedially with the genual gyrus (Figs. 5, 6).

The postcruciate gyrus was positioned caudodorsal to the cruciate sulcus, and its largest part could be seen on the medial aspect of the cerebral hemisphere, where it was bounded ventrally by the splenial sulcus. Dorsally, this gyrus was demarcated from the marginal gyrus by the ansate sulcus (Figs. 3, 5-7).

The diagonal gyrus was found on the lateral cerebral hemisphere dorsal to the prorean gyrus between the presylvian and diagonal sulci (Figs. 5, 6).

The composite gyri were represented by rostral and caudal portions. The rostral composite gyrus was a small gyrus found in the rostral part of the frontal lobe, rostrodorsal to the diagonal gyrus (Figs. 5, 6). While the caudal composite gyrus was the most caudoventral gyrus on the lateral cerebral hemisphere, and found ventral to the dorsal suprasylvian sulcus and occipital gyrus (Figs. 5, 6). On the right side of the cerebral cortex, this gyrus extended rostrally between the caudal sylvian and caudal ectosylvian gyri (Fig. 5).

The rostral sylvian gyrus was a large gyrus located nearly at the midpoint of the lateral cerebral hemisphere dorsal to the sylvian fissure. Moreover, this gyrus appeared M-shaped and surrounded by the suprasylvian and ectosylvian sulci (Figs. 5, 6).

The caudal sylvian gyrus was located in a triangular space made by the oblique gyri ventral to the caudal ectosylvian sulcus and dorsal to the pyriform lobe (Fig. 4).

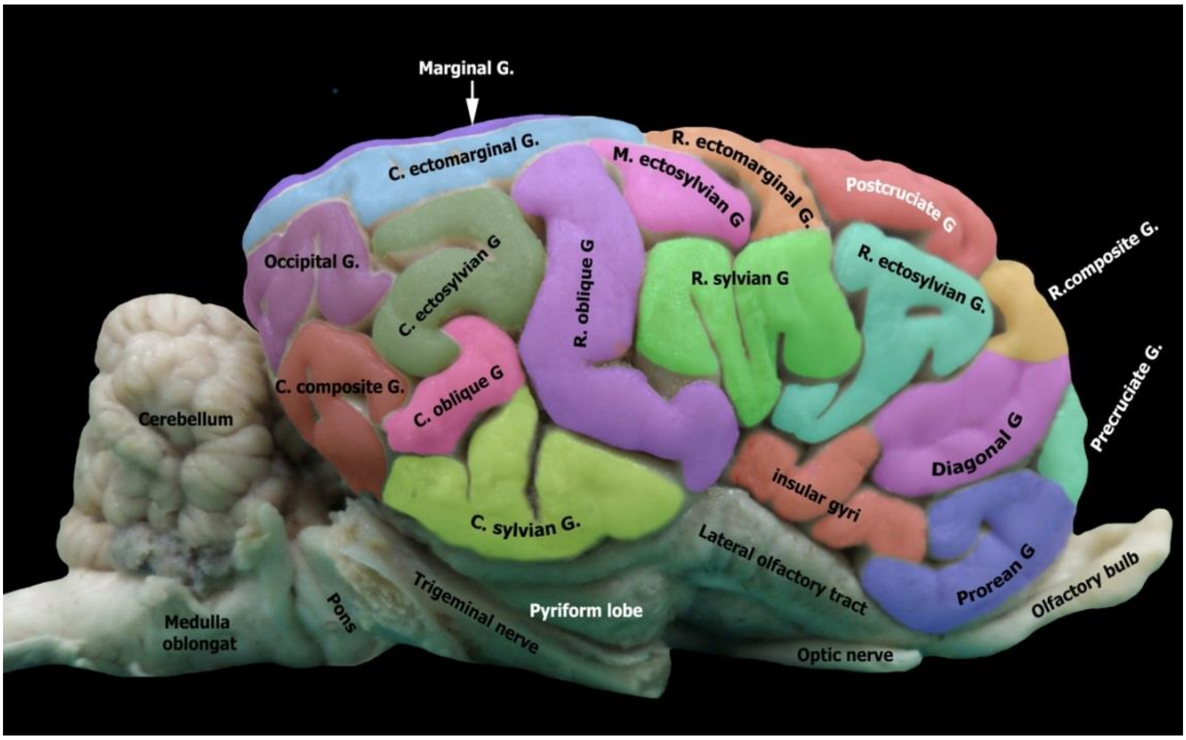

Figure 5: Lateral view of the right cerebral hemisphere of donkey, the colored illustrations showed the gyri of the lateral surface.

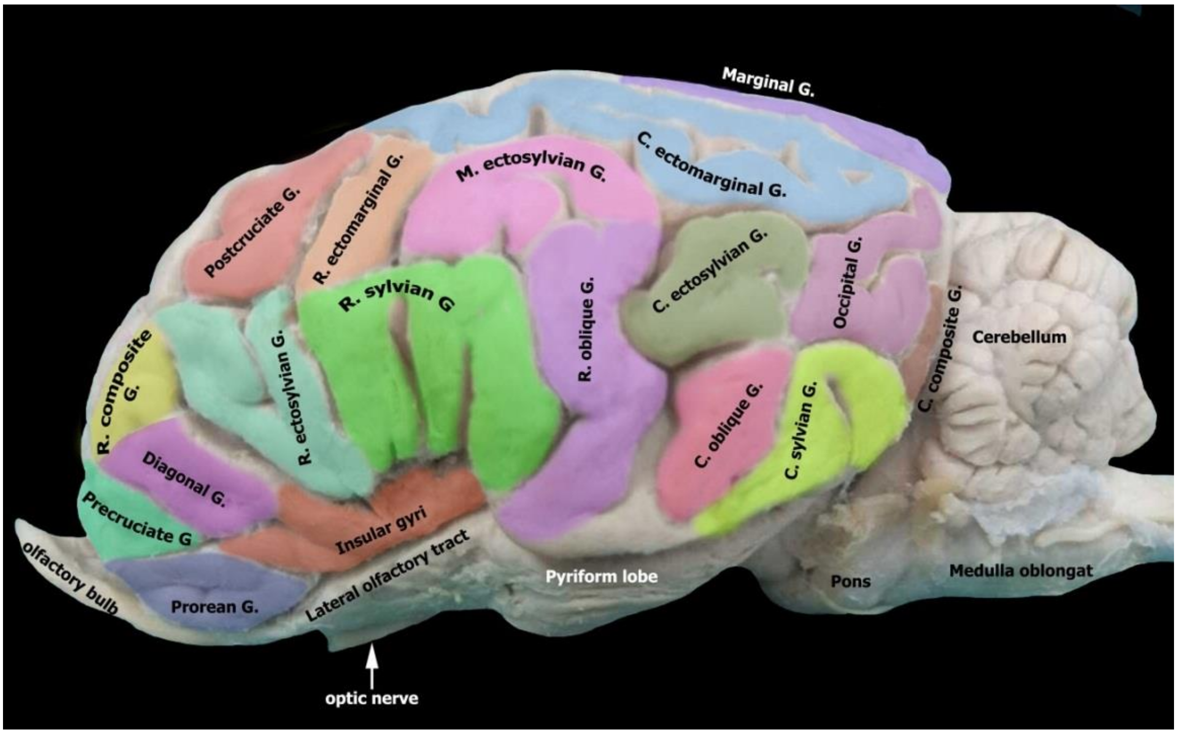

Figure 6: Lateral view of the left cerebral hemisphere of donkey, the colored illustrations showed the gyri of the lateral surface.

The ectosylvian gyri were constituted by three divisions: rostral, middle, and caudal, surrounding the sylvian fissure and middle sylvian gyrus. The rostral ectosylvian gyrus was found ventral to the rostral suprasylvian sulcus between the diagonal gyrus rostrally and the rostral sylvian gyrus caudally. On the right side of the cerebral cortex, the latter gyrus appeared hammer-shaped (Fig. 5), while on the left side, it appeared as a V-shape (Fig. 6). The middle ectosylvian gyrus was a small gyrus found ventral to the middle suprasylvian sulcus and dorsal to the rostral sylvian gyrus (Fig. 5). However, on the left side of the cerebral cortex, the middle ectosylvian gyrus appeared as an inverted double U-shape (Fig. 6). The caudal ectosylvian gyrus was an S-shaped gyrus located ventral to the caudal suprasylvian sulcus and between the rostral oblique gyrus rostrally and occipital gyrus caudally (Figs. 5, 6).

Table 2: Mean ± standard deviations of the length and width of the gyri on the right and left sides of the cerebral cortex in 15 adult donkeys.

	Length (cm)		Width (cm)	
	On right side	**On left side**	**On right side**	**On left side**
Prorean gyrus	1.68 ± 0.13	1.66 ± 0.18	1.30 ± 0.21	0.96 ± 0.27
Precruciate gyrus	1.98 ± 0.13	1.84 ± 0.18	0.78 ± 0.13	0.78 ± 0.14
Postcruciate gyrus	2.92 ± 0.13	2.78 ± 0.13	0.94 ± 0.11	0.86 ± 0.11
Diagonal gyrus	1.84 ± 0.27	1.64 ± 0.12	1.20 ± 0.22	1.12 ± 0.31
Rostral composite gyrus	1.10 ± 0.15	1.12 ± 0.16	0.92 ± 0.14	0.88 ± 0.08
Caudal composite gyrus	1.24 ± 0.18	1.38 ± 0.08	1.26 ± 0.19	1.48 ± 0.10
Rostral sylvian gyrus	1.54 ± 0.18	1.52 ± 0.13	1.88 ± 0.13	2.00 ± 0.10
Caudal sylvian gyrus	1.12 ± 0.13	1.30 ± 0.14	1.14 ± 0.23	1.24 ± 0.18
Rostral ectosylvian gyrus	1.74 ± 0.15	1.48 ± 0.29	2.08 ± 0.14	2.10 ± 0.23
Middle ectosylvian gyrus	1.70 ± 0.25	1.90 ± 0.22	0.86 ± 0.11	0.84 ± 0.15
Caudal ectosylvian gyrus	3.96 ± 0.11	3.80 ± 0.14	1.78 ± 0.08	1.70 ± 0.20
Rostral oblique gyrus	3.24 ± 0.27	3.14 ± 0.33	0.90 ± 0.10	0.88 ± 0.16
Caudal oblique gyrus	1.40 ± 0.15	1.50 ± 0.15	0.44 ± 0.11	0.48 ± 0.16
Occipital gyrus	3.24 ± 0.23	3.30 ± 0.28	1.66 ± 0.24	1.76 ± 0.16
Insular gyrus	2.22 ± 0.19	2.36 ± 0.15	0.82 ± 0.13	0.84 ± 0.18
Marginal gyrus	6.02 ± 0.14	6.06 ± 0.19	0.68 ± 0.13	0.74 ± 0.08
Endomarginal gyrus	4.84 ± 0.26	4.94 ± 0.33	0.20 ± 0.10	0.22 ± 0.10
Rostral ectomarginal gyrus	5.00 ± 0.15	5.00 ± 0.21	1.88 ± 0.08	1.90 ± 0.15
Caudal ectomarginal gyrus	5.96 ± 0.11	5.98 ± 0.16	2.38 ± 0.19	2.40 ± 0.25
Supracallosal gyrus	4.98 ± 0.08	4.96 ± 0.25	0.22 ± 0.08	0.24 ± 0.08
Subcallosal gyrus	1.44 ± 0.11	1.46 ± 0.21	0.88 ± 0.08	0.96 ± 0.11
Genicular gyrus	2.20 ± 0.15	2.22 ± 0.19	0.50 ± 0.07	0.48 ± 0.08
Genual gyrus	1.76 ± 0.13	1.80 ± 0.12	0.88 ± 0.08	0.76 ± 0.08
Cingulate gyrus	10.48 ± 0.19	10.48 ± 0.21	1.86 ± 0.13	1.88 ± 0.22
Splenial gyrus	3.28 ± 0.19	3.28 ± 0.25	1.16 ± 0.11	1.16 ± 0.13

The oblique gyri included two segments: rostral and caudal. The rostral oblique gyrus was a large gyrus positioned obliquely on the lateral cerebral hemisphere between the rostral sylvian gyrus rostrally and caudal ectosylvian gyri caudally. In addition, this gyrus was bordered rostrally by the middle ectosylvian sulcus and caudally by the oblique and caudal ectosylvian sulci (Figs. 5, 6). While the caudal oblique gyrus was a small gyrus found between the caudal ectosylvian gyrus dorsally and the caudal sylvian gyrus ventrally on the right side of the cerebral cortex (Fig. 5). However, on the left side of the cerebral cortex, this gyrus separates between the rostral oblique gyrus rostrally and the caudal sylvian gyrus caudally (Fig. 6).

The occipital gyrus was the most caudal part of the lateral cerebral hemisphere, which was located between the caudal ectomarginal gyrus dorsally and the caudal composite gyrus ventrally (Figs. 5, 6).

The insular gyri were small gyri located on the lateral cerebral hemisphere between the sylvian fissure and the lateral rhinal sulcus. These gyri appeared with three branches: rostral, middle, and caudal (Figs. 5, 6).

The marginal gyrus was found on the dorsal cerebral hemisphere, extending from the ansate sulcus rostrally to the transverse fissure caudally, in parallel to the longitudinal fissure. Furthermore, this gyrus was outlined laterally by the marginal sulcus and medially by the endomarginal sulcus, partially encompass-ing the caudal part of the caudal ectomarginal gyrus (Figs. 3, 5-7).

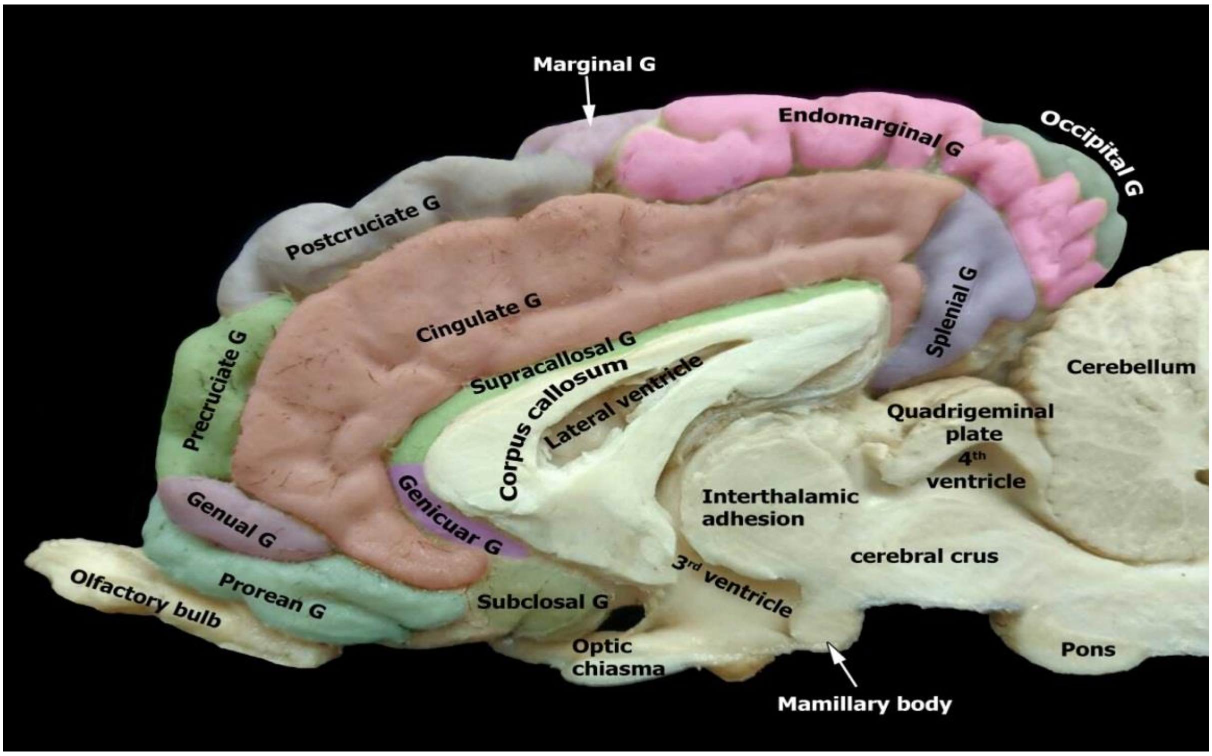

Figure 7: Medial view of the right cerebral hemisphere of a donkey, the colored illustrations showed the gyri of the medial surface.

The endomarginal gyrus intervened between the longitudinal fissure and the marginal gyrus. A significant part of this gyrus could be seen on the medial cerebral hemisphere (Figs. 3, 7).

The ectomarginal gyri were represented by rostral and caudal parts. The rostral ectomarginal gyrus was found on the dorsal cerebral hemisphere between the postcruciate and rostral ectosylvian gyri and the ansate sulcus, and it continued caudally with the caudal ectomarginal gyrus (Figs. 3, 5, 6). The later gyrus was a large gyrus which extended caudally in parallel to the marginal gyrus between the caudal suprasylvian sulcus ventrally and the caudal ectosylvian sulcus dorsally. It was noted that this gyrus showed several internal sulci dividing it into medial and lateral parts (Figs. 3, 5, 6).

The supracallosal gyrus was a thin gyrus located dorsal to the corpus callosum on the medial cerebral hemisphere. Moreover, this gyrus was bordered dorsally by the corpus callosal sulcus and continued ventral to the genu of the corpus callosum by the genicular gyrus (Fig. 7).

The subcallosal gyrus was a small gyrus located on the medial cerebral hemisphere, ventral to the genu of the corpus callosum and the geniculate gyrus (Fig. 7).

The genual gyrus was a small gyrus found ventromedial to the precruciate gyrus and was separated from the cingulate gyrus by the genual sulcus (Fig. 7).

The cingulate gyrus was the largest gyrus of the medial cerebral hemisphere that enveloped the corpus callosum. In addition, this gyrus was outlined dorsally by the splenial sulcus and ventrally by the corpus callosal sulcus (Fig. 7).

The splenial gyrus was a triangular gyrus found caudal to the splenium of the corpus callosum and the cingulate gyrus (Fig. 7).

DISCUSSION

The morphological identification and nomenclature of the gyri and sulci in equine is still scarce and incomplete (Cozzi *et al.,* 2014). Otherwise, the current study provided a comprehensive and novel insight into the normal architecture of the cerebral cortex in donkeys and admitted a color-coded map for the gyri and sulci in this species. Few previous studies tentatively described the architecture of the cerebral sulci in donkeys (Hifny *et al.,* 1985). Nevertheless, a clear overview of the cerebral architecture defining its gyri and sulci has been limitedly studied. Accordingly, in the current study, we attempted to explore comprehensively the exterior cerebral architecture with a precise description of the location, extension, and relations of its gyri and sulci in donkeys.

Mapping of the cerebral architecture to recognize and locate each gyrus and sulcus was sometimes complicated due to a lack of data and wide variability between animal species. This variability appeared clearly in the earlier studies in camel, where the same gyrus is labelled with different nomenclature; for example, the orbital, posterior sigmoid, and fornicalus gyri as described by Kanan (1973) match the prorean, post-cruciate, and dorsal cingulate gyri, respectively as mentioned by Xie *et al.* (2006) and Al Aiyan *et al.* (2024a). This variable mode of mapping among the same animal species has been taken into consideration during the identification of different gyri and sulci in our study, focusing on the gyrencephalic architecture in equine and comparing our findings with other animals. Furthermore, these differences in the mapping of the gyri and sulci could be observed between the right and left sides of the hemispheres in the same animal species. In this regard, our findings observed that the depth and extension of the sulci and folding of the gyri varied in the same individual specimens. These results concur with those of Thompson *et al.* (1996), proposing that the right and left hemispheres can carry gyri and sulci with different sizes and shapes in the same animal species.

However, the cerebral cortex in donkeys showed an asymmetry in its surface architecture; the color-coded atlas achieved in this study provided a precise localization of a distinct chain of sulci with clear length, depth, and extension. These topographic configurations of sulci landmarks provided a helpful guide for the neocortex architecture in donkey. Although the cerebral sulci were early described in donkey by Hifny *et al.* (1985), several sulci were not mentioned and were not thoroughly described in this study, including the diagonal and suprasplenial sulci. Based on our results, the sylvian fissure of the donkey brain was a prominent groove at the midpoint of the lateral cerebral hemisphere, indicating the boundaries of the frontal, temporal, and parietal lobes. Moreover, this groove ascended dorsally from the lateral cerebral sulcus in a narrow width with three branches: rostral, middle, and caudal. This trajectory of the sylvian fissure was previously reported in donkey (Hifny *et al.,* 1985), horse (Schmidt *et al.,* 2019), and camel (Al Aiyan *et al.,* 2024a). However, the sylvian fissure exhibited a deeper extension, approximately reaching the middle of the lateral cerebral hemisphere in bovine (Louw, 1989). In agreement with observations of Al Aiyan *et al.* (2024a) in camels, the ectosylvian sulcus consisted of three segments: rostral, middle, and caudal, forming an interrupted arch around the sylvian gyri and sylvian fissure. In contrast, the three divisions of this sulcus continued with each other in donkey (Hifny *et al.,* 1985), horse (Constantinescu and Schaller, 2018), and dog (Al Aiyan *et al.,* 2024b). Concerning the coronal sulcus, our study and that of Hifny *et al.* (1985) revealed that the coronal sulcus couldn't be observed in the donkey brain, where this sulcus is thought to be peculiar to the canine brain (Constantinescu and Schaller, 2018); otherwise, it could be demonstrated in the camel brain (Al Aiyan *et al.,* 2024a). In addition, some sulci, including endomarginal and callosomarginal sulci, are peculiar to the camel brain (Al Aiyan *et al.,* 2024a) and could not be observed in this study or other animal species (Hifny *et al.,* 1985; Louw, 1989; Constantinescu and Schaller, 2018; Schmidt *et al.,* 2019). Moreover, the sylvian sulci demonstrated in this study, including the suprasylvian and ectosylvian sulci, appeared well-developed with extensive divisions and complex pathways, demarcating the borders of most gyri in the lateral and dorsolateral aspects of the cerebral cortex. Meanwhile, these sulci exhibited simple pathways and less complex extensions in bovine Louw (1989), camel (Xie *et al.,* 2006; Al Aiyan *et al.,* 2024a), canine (Pascalau *et al.,* 2016), and feline (Pascalau *et al.,* 2016).

The cerebral cortex and its pattern of gyrification in mammals are thought to be incorporated with the intelligence and emotional behaviour (Kaas, 1995; Dunbar, 1998). The donkey brain under investigation shared similar characteristics with other mammals in the extensive gyrification pattern of the neocortex (Hofman, 1985; Xie *et al.,* 2006; Abdel Maksoud *et al.,* 2021). This pattern of intense gyrification is peculiar to ungulates and is correlated to increased body weight (Hofman, 1985). Otherwise, in comparison to the other mammals with the same body weight, the ungulates' brains showed more gyrification (Pillay and Manger, 2007). Moreover, among the ungulates, the neocortex exhibited a variable folding pattern regardless of body weight, where the horse brain is observed with more folding and intense cortical thickness than that of camel (Cozzi *et al.,* 2014), suggesting that the gyrification pattern in mammals is species-specific rather than body weight specific.

Our findings revealed an intense folding of the gyri in donkeys' brain, displaying the characteristic equine brain features. Moreover, the description and detailed nomenclature of these gyri in the current study were based on previous identification of the sulci separating them. In this regard, the present study reported that the cingulate gyrus was a large and extensive gyrus representing most of the medial aspect of the donkey neocortex. This pattern of cingulum folding might be peculiar to the equine species, as previously mentioned in donkey (Oto and Haziroglu, 2009) and horse (Pascalau *et al.,* 2016; Constantinescu and Schaller, 2018; Schmidt *et al.,* 2019). However, this gyrus exhibited a much smaller size in other mammals: camel (Xie *et al.,* 2006; Al Aiyan *et al.,* 2024a), bovine (Louw, 1989), canine (Pascalau *et al.,* 2016; Johnson *et al.,* 2020; Al Aiyan *et al.,* 2024b), and feline (Pascalau *et al.,* 2016). In addition, our study revealed two oblique gyri between the sylvian and ectosylvian gyri; such gyral features are characteristic of horses (Constantinescu and Schaller, 2018; Schmidt *et al.,* 2019), and are absent in bovine (Louw, 1989), camel (Xie *et al.,* 2006; Al Aiyan *et al.,* 2024a), canine (Pascalau *et al.,* 2016; Johnson *et al.,* 2020; Al Aiyan *et al.,* 2024b), and feline (Pascalau *et al.,* 2016). The ectomarginal gyrus in the current investigation and in camel (Al Aiyan *et al.,* 2024a) is represented by two divisions: rostral and caudal. However, this gyrus appeared with three sections in horses: rostral, middle, and caudal (Constantinescu and Schaller, 2018) and one section in canines (Al Aiyan *et al.,* 2024b). Moreover, the present study demonstrated two composite gyri: rostral and caudal. The rostral one is found in the most rostrodorsal part of the frontal lobe, while the caudal one is located in the most caudoventral part of the occipital lobe. These findings are similar to those observed in other domestic animals (Constantinescu and Schaller, 2018) and canine (Al Aiyan *et al.,* 2024b); however, these gyri could not be observed in the camel brain (Al Aiyan *et al.,* 2024a).

CONCLUSION

The present study provided a comprehensive morphological description of the sulci and gyri in the exterior cerebral cortex of donkeys' brain in the form of a color-coded map. This map established a reference dataset for donkey brain anatomy, which could help with further comparative neuroanatomy and neurological studies in this species.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

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تخطيط البنية الخارجية للدماغ الخارجية في الحمار (***Equus asinus***)

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"يعد التحديد الشكلي لقشرة المخ أمرًا بالغ الأهمية للتعرف على الوظائف المختلفة للمخ ورسم خرائطها. ان الهدف من هذه الدراسة هو الوصف التشريحي العام للتلم والتلافيف في القشرة المخية الخارجية لمخ الحمار. ولتحقيق هذا الهدف، استخدمنا خمسة عشر رأسًا من جثث حمير بالغة سليمة وخالية من الاضطرابات العصبية. تم حفظ هذه الرؤوس في محلول فورمالين ١٠٪ لمدة أسبوعين، ثم تم تشريحها بعناية لاستخراج المخ. كما تم فحص القشرة المخية لهذه العينات بدقة لتحديد الشكل والموقع ونمط الامتداد لكل تلفيف وتلم. كما تم كذلك وصف التلافيف والتلم التي تم تحديدها باختصار في خريطة ملونة تمثل الطبوغرافيا الخارجية للقشرة المخية. بالإضافة إلى ذلك، تم تسجيل قياسات كل من التلافيف والتلم على الجانبين الأيمن والأيسر من القشرة المخية. هذا وكشفت النتائج في هذه الدراسة عن وجود تشكيلات واسعة وضخمة من التلافيف والتلم في قشرة مخ الحمار. علاوة على ذلك، تم مقارنة التلافيف والتلم التي تم تحديدها بالمصطلحات الموضحة سابقًا، والتي أظهرت تشابهًا كبيرًا مع تلك الموجودة في الحصان مع بعض الاختلافات، خاصة في امتداد التلم ونمط تشكيل التلافيف. كما أظهر التحليل الإحصائي وجود قياسات متباينة نسبيا للتلافيف والتلم بين الجانبين الأيمن والأيسر من القشرة المخية مع عدم وجود فرق كبير بينهما ($P>0.05$). هذا ويمكن أن تعبر الخريطة الملونة للقشرة المخية التي تم انشائها في هذه الدراسة كمرجع أساسي لمزيد من الدراسات العصبية في الحمار".