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Cat Brain Neuroanatomy using Cryosectioning, Magnetic Resonance and Computed Tomography Imaging Modalities

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ABSTRACT

Magnetic resonance imaging (MRI) and computed tomography (CT) imaging modalities are invaluable for the diagnosis and treatment of neurological diseases. This study aimed to correlate the anatomical sectional data of the cats' brain to the sections obtained by both MRI and CT examination. The present work was conducted on four cats, 1-4 years old, weighing about (2.5 to 3.5) kg admitted to the hospital with terminal diseases not related to the nervous system. The anatomical sections were taken at intervals of 5 mm, on different planes such as sagittal, frontal and transverse. The sections were obtained, following humane euthanasia, from frozen heads and identified according to the previous literatures. The images from both MRI and CT were compared with those of the gross anatomy sections and different structures were identified. To identify arterial distribution in the brain, one cat was injected with red latex through the common carotid artery, frozen, and sectioned. For vascular imaging, the same cat was examined by MRI after intravenous injection of contrast media. The descriptions of the brain anatomy from the MRI and CT images will act as a basis for the diagnosis and treatment of different neurological diseases in cat. This will assist veterinarians and radiologists in the identification of various nervous lesions related to the brain.

Key words: Cat, Brain, Magnetic resonance imaging, Computed tomography, Anatomy

INTRODUCTION

Cats are one of the most popular pets in the world. With the high increase in its number, there is a growing need for new techniques such as CT and MRI, for diagnosis of their diseases (Bishop *et al.*, 2008 and Taeymans *et al.*, 2008). Well-defined, high-quality sectioned images are necessary for accurate interpretation of MRI and CT scans of cats (Rivero *et al.*, 2005; Lauridsen *et al.*, 2011).

This study was performed on healthy cats' heads to document the detailed anatomical structures of the brain. This knowledge was essential for the interpretation of images obtained by CT and MRI, which acted as a standard model for the recognition of abnormalities and identifi-cation of brain lesions in various neurological conditions (Gutierrez-Quintana *et al.*, 2011 and Forterre *et al.*, 2006).

The main aim of this study is to provide high-quality sectioned images and to correlate these with images obtained during MRI and CT scans to assist veterinarians with disease diagnosis in cats' brain. The original anatomical planes of cats' head were obtained, and the detailed structures of cats' brain were identified. These are expected to be viewed as educational and training tools for clinical veterinary medicine and to enhance the value of practice in feline medicine (Park *et al.*, 2009).

The MRI and CT scans, along with the sectioned images of the cats' frozen head in normal color and with high resolution offer greater insights into our understanding of sectional anatomy (Spitzer & Whitlock, 1997; Dixon *et al.*, 2015) Comparing these sections with the clinical images was helpful in multiple ways (Schiemann *et al.*, 2000 and Nowinski *et al.*, 2012).

MATERIALS AND METHODS

The present study was conducted on four adult Shirazi cats of 1-4 years old, weighing about 2.5 kg to 3.5 kg admitted to the hospital for euthanasia for diseases not related to the nervous system. Cats were humanely euthanized by intravenous pentobarbital overdose (100mg/ kg Anapental, Sigmatec, Egypt) following the American Veterinary Medical Association Guidelines for Euthanasia.

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Prior to anesthesia, cats were put on standard feline formula (removed 12 hr. before anesthesia) and given free access to water (removed 2 hr. before anesthesia).

Prior to the MRI and CT scans, the cats underwent a physical examination and hematological study (complete blood count and serum chemistry) to ensure the animals were tolerating anesthesia. All cats were imaged under general anesthesia. Depending on the patient size, a 24- or 26-gauge catheter was placed within the cephalic vein. The anaesthetic protocol followed was dexmedetomidine (0.04mg/ kg, IM, Precedex®, Hospira, Lake Forest, USA) and ketamine (10mg/ kg, Ketamax, Rotexmedica, Trittau, Germany), and then maintained using isoflurane (Isoflurane-Sedico®, SEDICO, 6th October, Egypt) at 0.25-2% with 1L/min 100% oxygen to desired effect. Cats were placed in sternal recumbency for MRI scanning.

Computed Tomography (CT) of the head was performed using helical CT (TOSHIBA, Asteion 4, Japan) with the following technical parameters: 120 kV (peak), 150 mAs, with an image field of view (FOV) of 110 mm. Images were collected from picture archiving and communication system (PACS). RadiAnt Digital Imaging and Communications in Medicine (DICOM) Viewer (Version: 4.6.8.18460) was used for their study.

MRI of the head was performed using 0.3 T magnet (Siemens AG 2009, Syngo MR A35, ID: 008). All images were obtained with a brain circular coil in three planes: transverse (axial), sagittal, and dorsal with various sequences specifically for brain investigation (Table 1). One cat was injected with red latex through the common carotid artery prior to freezing for angiography.

Cats were humanely euthanized by intravenous pentobarbital overdose (100mg/kg Anapental, Sigmatec, Egypt) following the American Veterinary Medical Association Guidelines for Euthanasia.

The cats' heads were frozen at −20°C for 3 days. After removal of the skin and temporal muscles, a band saw was used to open the frontal and parietal bony fenestration and expose the brain, which was then dissected along with its major arterial blood supply. The anatomical sections were taken through three anatomical planes: sagittal, frontal, and transverse. The slices were taken at 0.5 cm thickness (Park *et al*., 2010).

The rostral surface of these sections rinsed with 10% ethyl alcohol and photographed. The images were compared with those obtained from the MRI and CT scans. The identification of the structures followed the literature, {Nomina Anatomica Veterinaria (I.C.V.G.A.N., 2017)}. The experimental protocol was approved by the ethical committee of the Faculty of Veterinary Medicine at Cairo University.

RESULTS

Based on the images produced in this study, we noted that the cat's brain was divided into three parts: cerebrum, cerebellum, and brain stem. The cerebrum constituted the greater part of the brain and comprised of two cerebral hemispheres (Fig1). The cerebrum had an irregular surface with convoluted folds called gyri separated by grooves termed sulci. The right and the left cerebral hemispheres separated by the deep dorsal longitudinal cerebral fissure (central sulcus) (Fig. 1). The cerebrum was separated from the cerebellum by the transverse fissure (Fig. 1). The surface of the cerebellum was complex with a highly folded surface comprising folia separated by sulci. It was composed of the vermis, median part of the cerebellum, and two cerebellar hemispheres (Fig.1). The brain stem consisted of the pons (Fig.1) situated on the ventral surface of the brain represented as transverse elevated body, posterior to the cerebral peduncles (Fig. 2,3) and the medulla oblongata (Fig.4), which was considered to be the origin of the spinal cord (Fig. 1,4). Two small longitudinal bands, which bulged at the caudal margin of the pons were identified as the medullary pyramids of the medulla oblongata (Fig. 2), and a transverse band, the trapezoid body (corpus trapezoideum) (Fig. 4), was located just posterior to the pons.

The major cerebral structures identified in the cat's brain were the marginal gyrus (mg) (Fig. 3,4), supra sylvian gyrus (sg) (Fig. 3,4), and ectosylvian gyri (Fig. 1). The major cerebral sulci were identified as deepdorsal longitudinal cerebral fissure or central sulcus, lateral sulcus, supra sylvian sulcus (Fig. 1), and cruciate sulcus (Fig. 1, 3, 4). The cat's cerebrum was clearly divided into four lobes: frontal (f), parietal (p), temporal (t), and occipital lobes (o) (Fig. 1,2).

This study included six transverse anatomical sections, four frontal sections and three sagittal slices of the cats' brain. The identification of the main brain structures, as well as the comparison between the anatomical sections, MRI images, and CT images were all presented following a rostro-caudal direction of the brain.

Several landmarks were used to identify the brain parts in the MRI and CT images for comparison with images of the anatomical sections. These landmarks include the frontal bone (Fb) (Fig. 2,3), frontal sinus (fs) (Fig. 2), nasopharynx (np) (Fig.2), oropharynx (op) (Fig. 2), mandible (m) (Fig. 2), parietal bone (pb) (Fig. 2,3), auditory canal (ac) (Fig. 2,3), laryngeal cartilage (Lc) (Fig. 2), tympanic bulla (tb) (Fig. 2), the ethmoid bone (eb) (Fig. 3), and the internal sagittal crest (Ic) (Fig. 3).

Anatomy of cats' brain sections

Telencephalon: Images of the telencephalon clearly showed the cerebral hemisphere (Fig. 2/1) with frontal lobe (Fig. 1,2/f), olfactory bulb ((Fig. 2,3/2), olfactory tract (Fig. 2/3), the piriform lobe (Fig. 2/4), caudate nucleus (Fig. 2, 3,4/5) putamen (pu) (Fig. 3), external capsule (ec) (Fig. 3), and the corpus callosum (Fig. 2, 3,4/6). The latter was identified as a white structure consisting of fibers that connect the two cerebral hemispheres. Its anterior, curved part was the genu (Fig. 3,4/6a), its posterior part was the splenium (Fig. 3,4/6b), and between them dorsally was the trunk (body) (Fig. 3,4/6c) of the corpus callosum. The fornix (Fig. 2,4/7) curves anteroventrally from near the splenium. Some gyri were detected in the sagittal section including cingulate gyrus (cing), cruciate gyrus, and frontal gyrus (fg) (Fig. 4). Others could easily be traced in the frontal section: coronal gyrus (cg), composite gyrus (cog) and cruciate gyrus (Fig. 3).

Table 1: Parameters of MRI pulse sequences used for imaging of feline head

Sequence	TR (ms)	TE (ms)	FA	NEX	Echo Train Length	Slice thickness (mm)X Inter-slice spacing	Field of view	Acquisition Matrix	Time
T1 SE	728	25	90	2	1	3 X 3.6	150*150	358*512	5:25
T2 TSE	3780	86	180	2	7	3 X3.6	150*150	436*512	7:03
T1 FLAIR	6780	74	180	1	7	5 X 5.61	250*250	192*115	2:48

TR: Time of repetition, TE: Time of echo, FA: Flip angle, Number of excitations (averages), SE: spin echo, TSE: turbo spin echo, FLAIR: fluid attenuation inversion recovery, TOF: time of flight, MIP: maximum intensity projection.

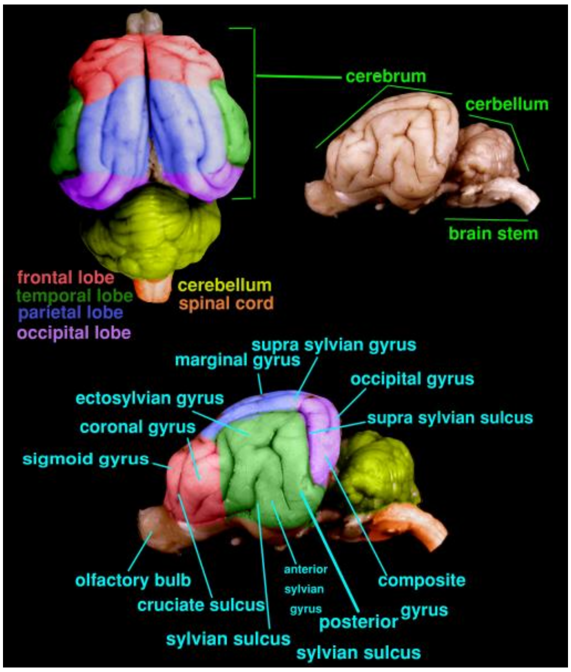

Fig. 1: photograph showing the colored cat brain showing lobes, gyri and sulci: f, frontal lobe; t, temporal lobe; p, parietal lobe; o, occipital lobe.

Diencephalon: In images of the diencephalon, the parietal lobe (Fig. 1,2/p), the optic chiasma (Fig. 4/ 8), optic nerve (Fig. 2/9), thalamus (Fig. 2,4/10), hypothalamus (Fig. 2,4/11), lateral ventricles (Fig. 3,4/12), third ventricle (Fig. 2,4/13), and the paired mammillary bodies (Fig. 4/14) were readily identified.

Mesencephalon: Images showed the cerebral peduncle (Fig. 2,3/15), corpora quadrigemina (Fig. 2,3,4/16), temporal lobe (Fig. 1,2/t), hippocampus (Fig. 2,4/17), occipital lobe (Fig. 1,2/o) and the cerebral aqueduct (Fig. 2/18).

Metencephalon: the cerebellum which consisted of the vermis (Fig.2, 3,4/19) and the two cerebellar hemispheres (Fig.2, 3,4/20), the fourth ventricle (Fig. 2,4/21) and the pons (Fig. 2,3,4/22) could readily be seen in images of the metencephalon.

Myelencephalon: These images showed the medulla oblongata (Fig. 4/23) connected to the spinal cord, the medullary pyramids (Fig. 2/24), and the trapezoid body (corpus trapezoideum) (Fig. 4/25).

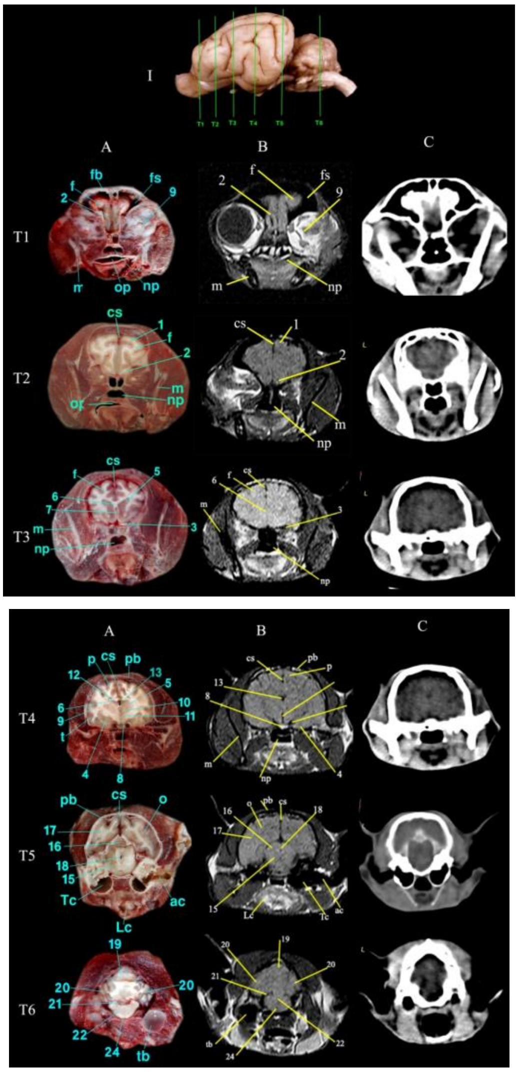

Fig. 2: photograph showing transverse sections of cat brain with CT and MRI: A, Anatomical sections; B, MRI; C, CT images 1, cerebral hemisphere; 2, olfactory bulb; 3, olfactory tract; 4, the piriform lobe; 5, caudate nucleus; 6, the corpus callosum; 9, optic nerve; 10, thalamus; 11, hypothalamus; 13, third ventricle; 15, the cerebral peduncle; 16, corpora quadrigemina; 17, hippocampus; 18, the cerebral aqueduct; 19, the vermis of cerebellum; 20, the cerebellar hemispheres; 21, the fourth ventricle; 22, pons; 24, the medullary pyramids; ac, auditory canal; Cs, central sulcus; f, frontal lobe; Fb, frontal bone; fs, frontal sinus; Lc, laryngeal cartilage; m, mandible; np, nasopharynx; o, occipital lob; op, oropharynx; p, parietal lobe; pb, parietal bone; t, temporal lobe; tb, tympanic bulla.

Arterial blood supply

In this study, the arterial blood supply to the cat's brain, based on the anatomical sections, was observed to consisted of three cerebral arteries: rostral, middle, and caudal. Blood supply to the brain was mainly from the *circulus arteriosus cerebri* known as the circle of Willis (CW) (Fig. 5), which was located ventral to the hypothalamus. The formation of the circle of Willis included both the basilar artery posteriorly and the two internal carotid arteries laterally.

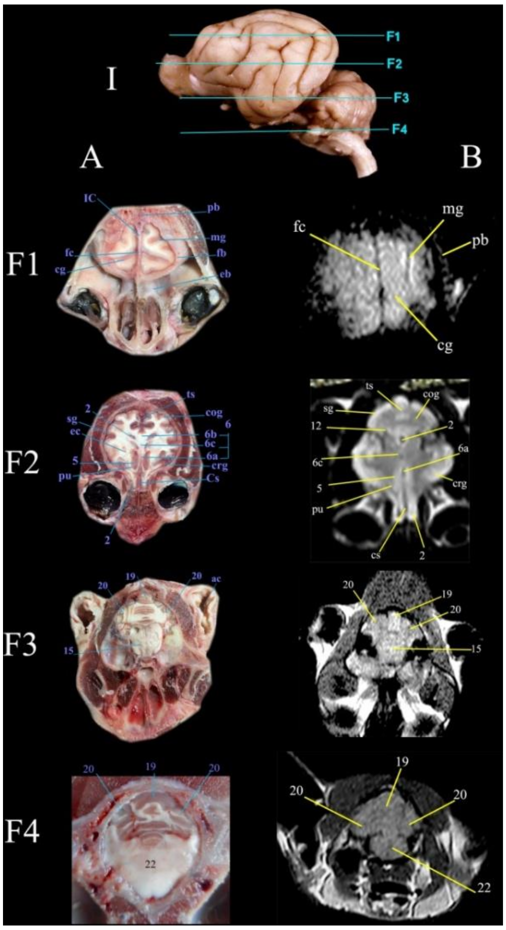

Fig. 3: photograph showing frontal sections of cat brain with CT and MRI: A, Anatomical sections; B, MRI; 2, olfactory bulb; 5,caudate nucleus; 6, the corpus callosum; 6a, the genu; 6b, the splenium; 6c, the trunk (body of corpus callosum); 12, lateral ventricles; 15, the cerebral peduncle; 16, corpora quadrigemina; 19, the vermis of cerebellum; 20, the cerebellar hemispheres; 22, pons; ac, auditory canal; cg, coronal gyrus; cog, composite gyrus; crg, cruciate gyrus; Cs, central sulcus; eb, ethmoid bone; ec, external capsule, Fb, frontal bone; fc, falx cerebri; Ic, internal sagittal crest; mg, marginal gyrus; pb, parietal bone; pu, putamen; sg, supra sylvian gyrus; ts, transverse fissure.

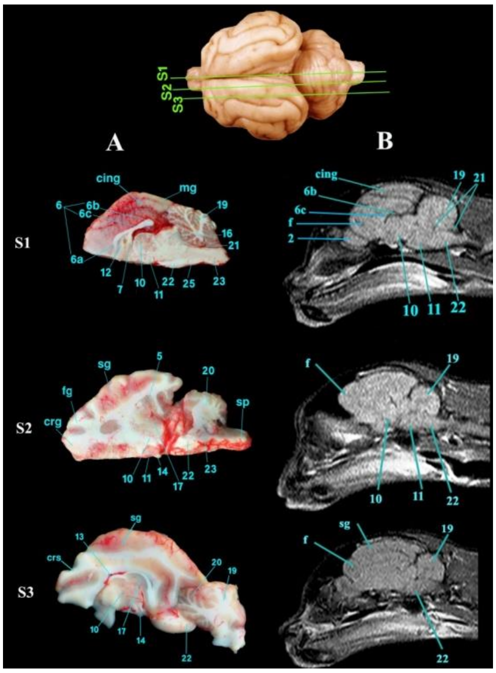

Fig. 4: photograph showing sagittal sections of cat brain with CT and MRI: A, Anatomical sections; B, MRI; 2, olfactory bulb; 5, caudate nucleus; 6, the corpus callosum; 6a, the genu; 6b,the splenium; 6c, the trunk (body of corpus callosum); 7, The fornix; 10, thalamus; 11, hypothalamus; 12, lateral ventricles; 13, third ventricle; 14, the paired mammillary bodies; 16, corpora quadrigemina; 17, hippocampus; 19, the vermis of cerebellum; 21, the fourth ventricle; 22, pons; 23, the medulla oblongata; 25, the trapezoid body (corpus trapezoideum); Cing, cingulate gyrus; crg, cruciate gyrus; crs, cruciate sulcus; f, frontal lobe; fg, frontal gyrus; mg, marginal gyrus; sg, suprasylvian gyrus; sp, spinal cord.

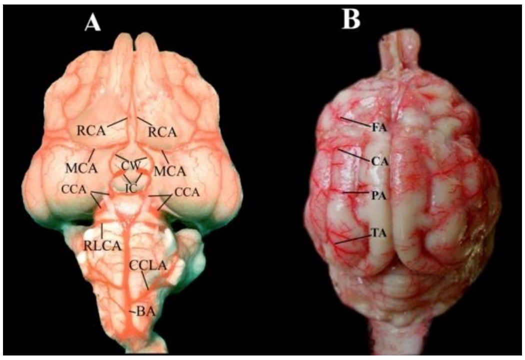

Fig. 5: photograph showing the arterial blood supply of cat brain: BA, basilar artery; CA, central artery; CCA, the caudal cerebral artery; CCLA, caudal cerebellar artery; CW, (the circle of Willis); FA. frontal artery; IC, The internal carotid artery; MCA, the middle cerebral artery; PA, parietal artery; RCA, The rostral cerebral artery; RCLA, rostral cerebellar artery; A, temporal artery.

The internal carotid artery (IC) (Fig. 5) was identified as a terminal branch of the common carotid that ran toward the base of the skull.The rostral cerebral artery (RCA) (Fig. 5) originated from the rostral border of the circle and passed medial to the medial olfactory tract. It supplied the falax cerebri (fc) (Fig. 3) and frontal dura with one major branch: the frontal artery (FA) (Fig. 5). Meanwhile, the anterolateral surface of the piriform lobe and the lateral surface of the cerebral hemispheres were supplied by the middle cerebral artery (MCA) (Fig. 5) and its dorsal branches: the central, parietal, and temporal arteries (Fig 5). The MCA anastomosed with several branches of the RCA and the caudal cerebral artery (CCA) (Fig. 5).

DISCUSSION

Structural information regarding the anatomy of cats' brain retrieved from the anatomical sections was compared with the images obtained from both MRI and CT scans.

Several studies (Nepomuceno et.al., 2016; Gutierrez-Quintana *et al*., 2011; Forterre *et al*., 2006) recommended the use of the CT imaging as a rapid and easy diagnostic method for brain injuries in cats; however, we found that the level of detail achieved in gross sectional anatomy and MRI images could not be matched in the CT image where the brain appeared as a homogenous gray mass with little differentiation in density. Our findings were supported by those of previous studies on the quality of CT images (Nepomuceno *et.al.*, 2016).

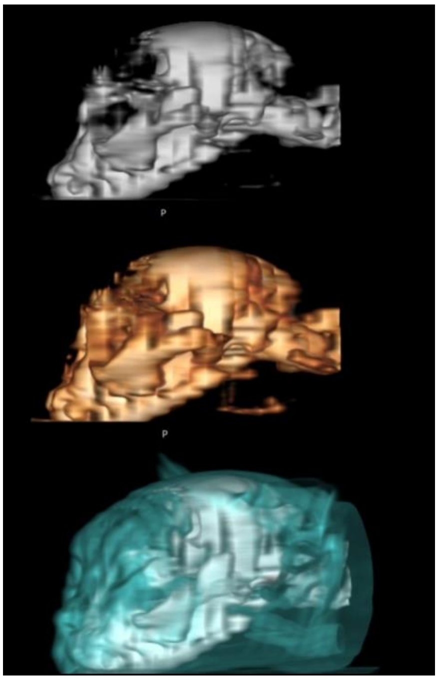

Fig. 6: Surface model of cat head with reconstructed images from CT scaning.

The cats' brain appeared to have similar structure to that of the dog except for the smaller size. This supporting evidence reported in previous anatomical studies in cat Nepomuceno *et.al.*, 2016 and in dog Uemura, 2015.

Our results identified the major cerebral structures; the marginal, suprasylvian and ectosylvian gyri and the major cerebral sulci; deep dorsal longitudinal cerebral fissure (central sulcus), lateral sulcus and supra sylvian sulcus. Similar results were reported by (Smith *et al.*, 2001).

The surface of the telencephalon showing the sulci and gyri in both the anatomical sections and MRI; however, these were not clearly visible in the CT images. The gyri and sulci showed similar convolution to that reported in the dog studies by (Uemura, 2015) but were less convoluted than those of the brown bear (Sienkiewicz *et al.*, 2019).

The gyri frontalis recorded in the dogs was (Meyer, 1964; Uemura, 2015) couldn't be established in the cats' brain and this was supported by other cat studies (Kobry´n and Kobry´nczuk, 2004 and Smith *et al*., 2001). The sulcus cruciatus minor recorded in both dogs (Meyer, 1964) and brown bear (Sienkiewicz *et al*., 2019) wasn't found in this study.

The putamen could be identified in both sectional images and MRI images and was similar to what had been reported in dogs (Mogicato *et al*., 2011) and brown bears (Sienkiewicz *et al*, 2019). As previous reported for cats (Gray-Edwards *et al*., 2014). The nucleus caudatus in this study were similar, in proportion to telencephalon to those of dogs (Mogicato *et al*., 2011), brown bear (Sienkiewicz *et al*, 2019) and ferret (Sawada *et al*., 2013) The septum pellucidum which presented as a short structure in the dog (Fletcher, 2007; Meyer, 1964) couldn't be detected in this study. This was reported also to be the case in other cat (Gray-Edwards *et al*., 2014) and in brown bear (Sienkiewicz *et al*, 2019).

Unlike dogs, the cerebellum could be easily seen from the dorsal surface as supported by previous studies (Smith *et al*., 2001). The medulla oblongata appeared somewhat rounded in cross-section for cats, in accordance with (Welker *et al*., 2009). In contrary, the medulla was dorsoventrally flattened in dog (Whalen, 2003) and brown bear **(**Sienkiewicz *et al*, 2019).

The arterial blood supply to the cats' brain was identified in this study as comprising three cerebral arteries; rostral, middle and caudal. These observations matched those of previous MRI studies (Gray-Edwards *et al*., 2014).

The rostral cerebral artery and the middle cerebral artery anastomosed then the middle cerebral artery communicated with the caudal cerebral artery. This provided a powerful collateral circulation in case of blood vessel blockage as described in previous study (Vander Eecken, 1953).

These finding could be used as a guide for diagnosis of lesions in cats' brain using both MRI and CT images as had been suggested by previous studies (Nepomuceno et.al., 2016 and Troxel *et al*., 2003).

The cat model offered many insights into the anatomy of cats' brains and the potential usefulness and limitations of MRI and CT scans in the diagnosis and treatment of neurological diseases as that mentioned in (Gutierrez-Quintana *et al*., 2011). Detailed anatomical structures obtained using technologies, such as CT and MRI, might lead to improved diagnosis of various forms of epilepsy (Woermann and Vollmar, 2009) multiple sclerosis (Wattjes *et al*., 2006) and other neurological disorders.

Conclusion

The obtained results could be used as a guide for veterinarians concerned with the cat neurological diseases. The cats' brain structure was most clearly elucidated through anatomical sections and MRI imaging, whereas CT images lacked the differentiation and definition achieved by the other two techniques. The results of this paper indicated that MRI provided a reliable method for the diagnosis of alterations in cats' brains, particularly when accompanied by physical and neurological examinations.

Author contributions

All authors had been equally participated in the work.

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