ORIGINAL ARTICLE

Computed tomographic imaging of the brain of normal neonatal foals

Tomografía computarizada del cerebro en potrillos neonatos

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RESUMEN

El objetivo de este estudio fue proporcionar una descripción detallada de la anatomía normal del cerebro de potrillos neonatos y de las estructuras asociadas mediante tomografía computarizada (TC) y cortes anatómicos. Se utilizó un escáner de cuarta generación y se adquirieron imágenes transversales con un grosor de dos milímetros. Tras el estudio por TC, los animales fueron sacrificados por razones no relacionadas con patologías de la cabeza. Para ayudar en la identificación precisa del cerebro y las estructuras asociadas, las imágenes de TC fueron comparadas con las correspondientes secciones de la cabeza. Las imágenes de TC se correlacionaron de buena manera con sus correspondientes secciones anatómicas, mostrando una buena diferenciación entre el tejido óseo y el tejido blando de la cabeza. Las imágenes obtenidas mediante TC pretenden ser una referencia anatómica inicial para la interpretación de los estudios clínicos del cerebro y las estructuras asociadas en potros vivos recién nacidos.

Palabras clave: tomografía computarizada, anatomía, cerebro, potro neonato.

SUMMARY

The aim of this study was to provide a more complete description of normal cross-sectional anatomy of the neonatal brain of the foal and associated structures by computed tomography (CT) and gross anatomical sections. Using a fourth-generation CT scanner, 2-mm contiguous transverse images were acquired from two neonatal 5-days-old Quarter horse foals. After the study the animals were euthanised for reasons unrelated to head pathology. To assist in the accurate identification of brain and associated structures, transverse CT images were obtained and compared with the corresponding frozen cross-sections of the head. CT images matched well with their corresponding transverse gross sections and provided good differentiation between the bones and the soft tissues of the head. These CT images are intended to be a useful initial anatomic reference in the interpretation for clinical CT imaging studies of the brain and associated structures in live neonatal foals.

Key words: computed tomography, anatomy, brain, neonatal foal.

INTRODUCTION

In the last years, the use of modern images techniques such as computed tomography (CT) or magnetic resonance imaging (MRI) has greatly improved the way of making a diagnosis in veterinary medicine. CT is a non-invasive imaging modality that provides excellent spatial resolution and good discrimination between bone and soft tissue (Barbee *et al* 1987, Peterson and Bowman 1988). These characteristics are very useful to obtain anatomical information about different regions of the animal body. Most of the published reports deal with the normal description of cranioencephalic structures in small and large animals (Fike *et al* 1981, Kaufman *et al* 1981, Feeney *et al* 1991, George and Smallwood 1992, Solano and Brawer 2004). In equine medicine, the contribution of CT or MRI to anatomical and clinical knowledge is very limited due to the high cost and the

lack of suitable design of this equipment when treating older foals and adult horses. The CT scanners used in veterinary medicine are designed to use in human patients; therefore, this type of machines are only suitable for neonatal foals due to size constraints of the CT gantry and scanning table. Due to all these limitations, reports of CT in the horse have been focused on technical procedures (Barbee *et al* 1987), studies of the head (Vink-Nooteboom *et al* 1998, Morrow *et al* 2000, De Zani *et al* 2010), distal extremities (Peterson and Bowman 1988) and cervical spine (Zafra *et al* 2012). However, most of these studies were performed on cadaver specimens, but to the author's knowledge similar CT studies in live neonatal foals have not been reported.

The aim of this study was to provide a more detailed description of the normal cross-sectional anatomy of the equine neonatal brain and associated structures using CT images and transverse gross anatomic sections. These CT images are intended to be a useful and complementary anatomic reference for clinical studies of the head of neonatal foals such as fractures, malformations, hydrocephalus and other neurological disorders.

MATERIAL AND METHODS

CT images were obtained from two neonatal 5-days-old Quarter horse foals. Before the evaluation of the head by CT, the animals were pre-anesthetised with xylazine at 0.5 mg/kg, IV (Rompun®, Bayer HealthCare AG, Germany). The anesthesia was induced with a bolus of propofol at 2.0-2.5 mg/kg IV (Diprivan®, AstraZeneca, UK) administered through a jugular catheter. An infusion of propofol (0.2-0.4 mg/kg IV) was initiated after intubation. The infusion rate was regulated to maintain immobilization without over anaesthetising the foal. The foals were intubated with a cuffed endotracheal tube to maintain an airway. Anesthetised foals were placed in sternal recumbence on the scanning table. Foals were monitored by counting respiratory and pulse rates. A serie of 2-mm thick transverse CT images from the occipital condyles to the olfactory bulb was obtained with a fourth generation CT equipment (General Electric Medical System, Milwaukee, WI). The parameters used for CT imaging were 120 kVp, 560 mAs. A soft tissue window setting (WW = 190; WL = 35) was applied. After CT study, the foals were euthanised for reasons unrelated to head diseases. This protocol was done following the recommendations approved by the Ethical Committee of the Veterinary Faculty of Las Palmas de Gran Canaria University (Protocol 52/2009). To better evaluate CT images, the heads were frozen and sectioned (10 mm thick), using an electric saw with the slabs cut transversely to correspond with the CT images. All sections were cleaned, photographed and replaced in the freezer for future studies. CT images that most closely matched each gross section were compared to the corresponding gross anatomic sections and textbooks of anatomy (Feeney *et al* 1991, Vazquez Auton *et al* 1992, Schaller 2007) to identify the normal anatomy of the central nervous system and associate structures of the head.

RESULTS

Six CT images with their corresponding transverse cryosections were presented from caudal to rostral progression, from the level of the myelencephalon (figure 1) to the level of the olfactory bulbs (figure 6). The CT images were displayed to the viewer's left, whereas the gross anatomic sections were displayed to the viewer's right. No internal head lesions were seen on CT images. Clinically relevant anatomic structures of the brain and associated structures were evaluated and labelled according to location and the characteristics of degree of attenuation of the different tissues. No anatomic or degree of attenuation variations were detected in the head of the two neonatal foals used in the study because of the similar size of the animals. The transverse CT images provided excellent depictions of anatomical structures of the brain. Detailed anatomy of the central nervous system and associated formations was acquired. Thus, bones of the head were easily identifiable by their high degree of attenuation compared to adjacent or surrounding structures, such as the paranasal sinuses, guttural pouch and encephalic ventricular system. Several structures of the central nervous system such as myelencephalon (figure 2), cerebellar vermis and hemispheres (figures 2-3), cerebral hemispheres (figures 3-7), hippocampus (figure 4), roof of mid-brain (figure 4), thalamus, hypothalamus and hyphophysis (figure 5), optic nerves (figure 6), olfactory bulb (figure 7), as well as the muscles of the head and glands showed intermediate degree of attenuation. Cerebrospinal fluid appeared black on the CT images and could be visualized in the ventricular system and the subarachnoid spaces. In addition to these structures, there are the eyeball and retrobulbar area, as well as different component of the ear were clearly seen.

DISCUSSION

In the present study, the CT images of the brain and associated structures of normal neonatal foals provided excellent detail of clinically relevant anatomy and correlated well with corresponding gross specimens. Some reports that described the normal anatomy of the equine head showed similar results (Arencibia *et al* 2000, Smallwood *et al* 2002, De Zani *et al* 2010). However, in most of these studies the normal anatomy of the brain was scarcely described.

Most of the anatomic atlases for tomographic imaging modalities are made by direct comparison between images obtained *in vivo* and the corresponding anatomic slices obtained *ex vivo*. Therefore, the use of live neonatal foals instead of cadaver specimens or isolated heads was an important aspect to consider. Several reports of CT imaging of the head used live animals (Hathcock *et al* 1995, Solano and Brawer 2004, Probst *et al* 2005), but they were not focused in the study of the brain anatomy. Other reports used isolated heads for the study of the equine adult head (Morrow *et al* 2000), the foal head (Smallwood *et al* 2002), and the paranasal sinuses of adult horses (De Zani *et al* 2010). In these studies there were soft tissue findings associated with post-mortem changes such as the brain retraction or enlargement of cerebral ventricles due to the effect of air-filled cavity. In contrast, in the present study, the normal appearance of the different structures of the central nervous system such as the hippocampus, the pineal gland or specific ear anatomic structures were better visualised. In addition, the use of contrast enhanced CT images provided more anatomic detailed information regarding to different encephalic structures such as the choroid plexus of the lateral ventricles or the falx cerebri that were not well identified by other CT studies (Arencibia *et al* 2000, Morrow *et al* 2000, Smallwood *et al* 2002).

Despite the higher usage in the last years of CT imaging in veterinary medicine, there are limiting factors such
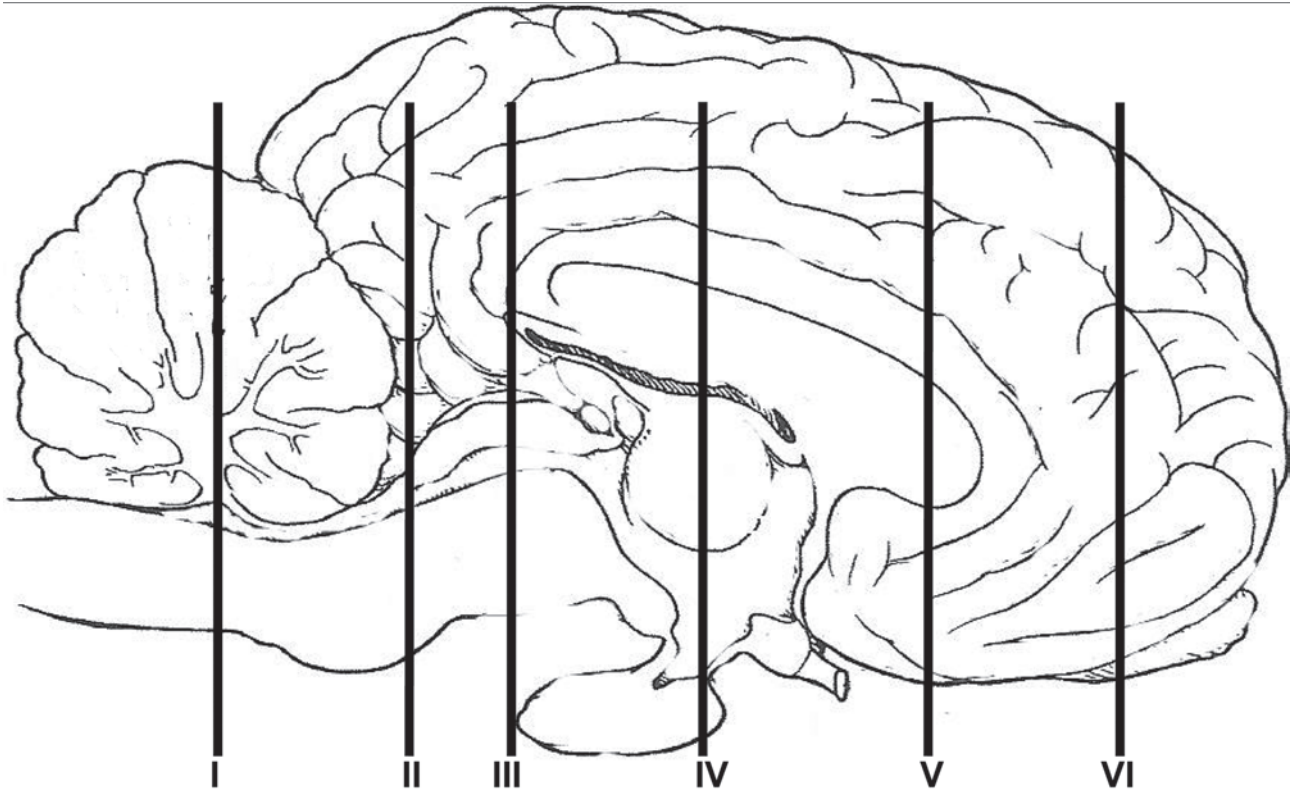
Figure 1. Representative image of equine brain. Each line and number (I-VI) represents the approximate level of the following transverse CT images (Figures 2-7).

Imagen representativa de un encéfalo equino. Cada línea y número (I-VI) representa el nivel aproximado de las TC transversales (Figuras 2-7).
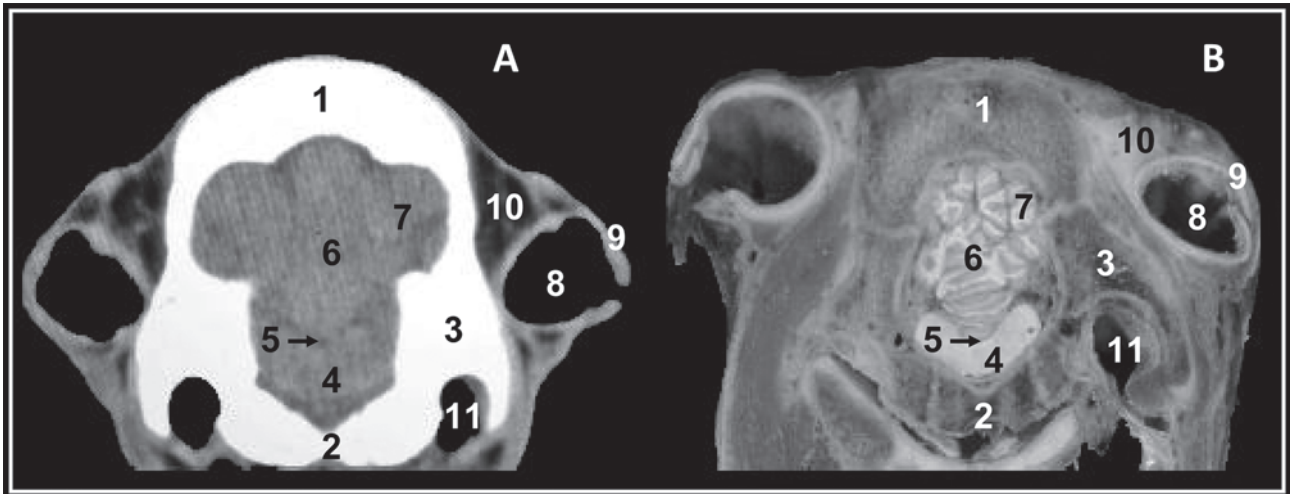

Figure 2. (A) Computed tomography image and (B) anatomic section at the level of myelencephalon. 1. Squamous part of occipital bone; 2. Basilar part of occipital bone; 3. Lateral part of occipital bone; 4. Myelencephalon; 5. Fourth ventricle; 6. Cerebellar vermis; 7. Cerebellar hemisphere; 8. Auricle; 9. Auricular cartilage; 10. Auricular fat; 11. Guttural pouch (caudal part).

(A) Imagen de tomografía computarizada y (B) sección anatómica a nivel del mielencéfalo. 1. Porción escamosa del hueso occipital; 2. Porción basilar del hueso occipital; 3. Porción lateral del hueso occipital; 4. Mielencéfalo; 5. Cuarto ventrículo; 6. Vermis del cerebelo; 7. Hemisferio del cerebelo; 8. Pabellón auricular; 9. Cartílago auricular; 10. Cuerpo adiposo auricular; 11. Bolsa gutural (parte caudal).
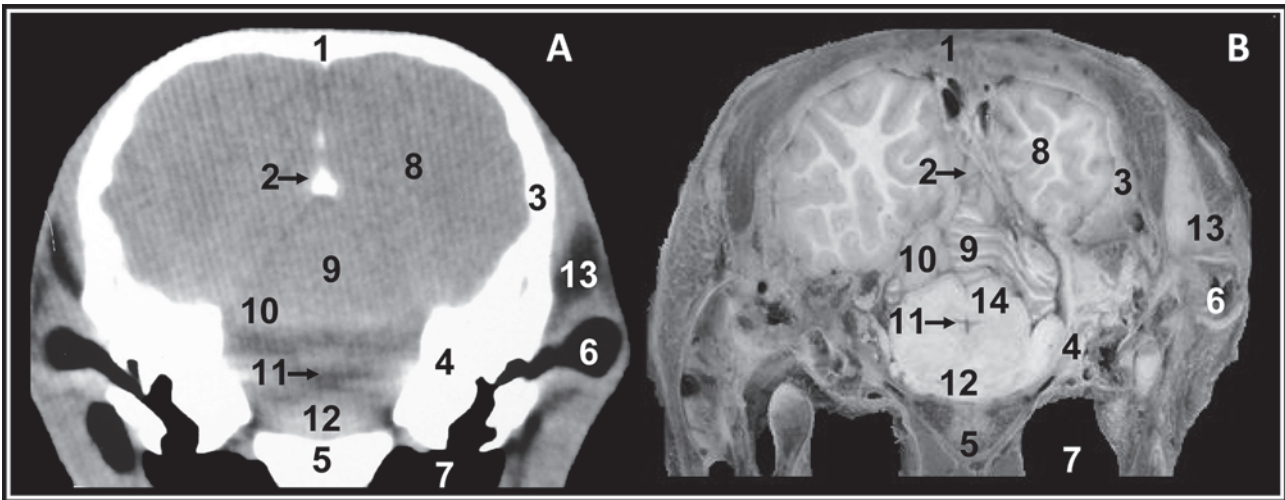
Figure 3. (A) Computed tomography image and (B) anatomic section at the level of pons. 1. Parietal bone; 2. Tentorium cerebelli osseum; 3. Squamous part of temporal bone; 4. Petrous part of temporal bone; 5. Basilar part of occipital bone; 6. External acustic meatus; 7. Guttural pouch; 8. Cerebral hemisphere: occipital lobe; 9. Cerebellar vermis; 10. Cerebellar hemisphere; 11. Fourth ventricle; 12. Pons; 13. Auricular fat; 14. Caudal collicule.

(A) Imagen de tomografía computarizada y (B) sección anatómica a nivel del puente. 1. Hueso parietal; 2. Tentorio óseo del cerebelo; 3. Porción escamosa del hueso temporal; 4. Porción petrosa del hueso temporal; 5. Porción basilar del hueso occipital; 6. Meato acústico externo; 7. Bolsa gutural; 8. Hemisferio cerebral: lóbulo occipital; 9. Vermis del cerebelo; 10. Hemisferio del cerebelo; 11. Cuarto ventrículo; 12. Puente; 13. Cuerpo adiposo auricular; 14. Colículo caudal.
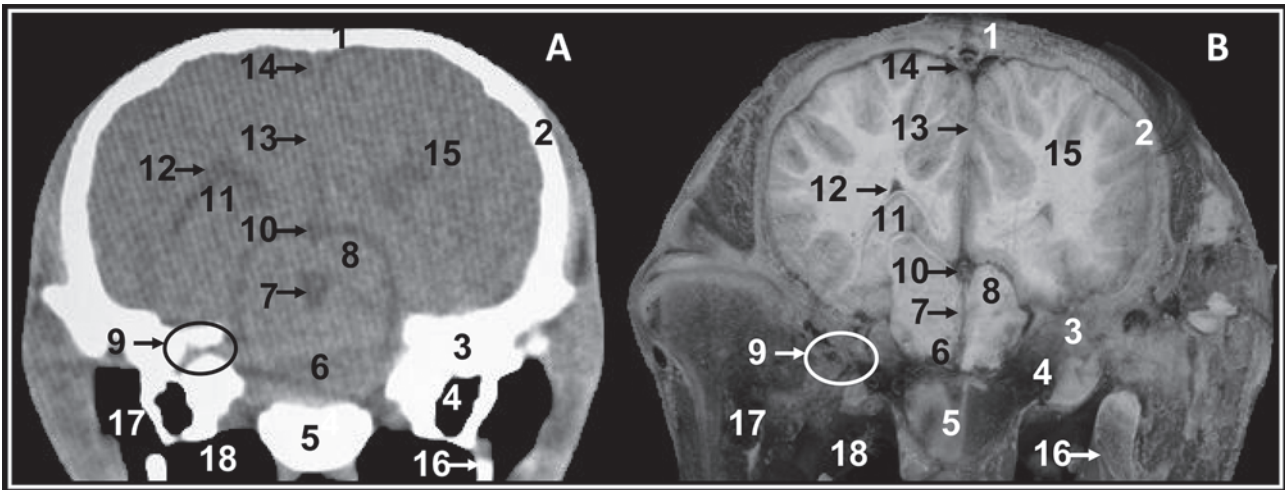

Figure 4. (A) Computed tomography image and (B) anatomic section at the level of mesencephalon. 1. Parietal bone; 2. Squamous part of temporal bone; 3. Petrous part of temporal bone; 4. Tympanic cavity; 5. Body of basisphenoid bone; 6. Cerebral peduncle; 7. Mesencephalic aqueduct; 8. Mesencephalic collicule; 9. Internal acoustic meatus; 10. Third ventricle; 11. Hippocampus; 12. Lateral ventricle; 13. Cerebral longitudinal fissure; 14. Dorsal sagittal sinus; 15. Cerebral hemisphere: temporal lobe; 16. Stylohyoid bone; 17. Guttural pouch: lateral recess; 18. Guttural pouch: medial recess. .

(A) Imagen de tomografía computarizada y (B) sección anatómica a nivel del mesencéfalo. 1. Hueso parietal; 2. Porción escamosa del hueso temporal; 3. Porción petrosa del hueso temporal; 4. Cavidad timpánica; 5. Cuerpo del hueso basiesfenoides; 6. Pedúnculo cerebral; 7. Acueducto del mesencéfalo; 8. Colículo del mesencéfalo; 9. Meato acústico interno; 10. Tercer ventrículo; 11. Hipocampo; 12. Ventrículo lateral; 13. Fisura longitudinal del cerebro; 14. Seno sagital dorsal; 15. Hemisferio cerebral: lóbulo temporal; 16. Hueso estilohioides; 17. Bolsa gutural: receso lateral; 18. Bolsa gutural: receso medial.

as the cost, limited availability and the physical size of some large animals such as older foals and adult horses that influence its usage in equine medicine. However, for neonatal foals, CT may be a clinically useful and effective imaging modality to study selected cases such as skull fractures, malformations, hydrocephalus, neonatal encephalopathy and hypoxic ischemic encephalopathy (MacKay 2005, Dickey *et al* 2011). In the future would be
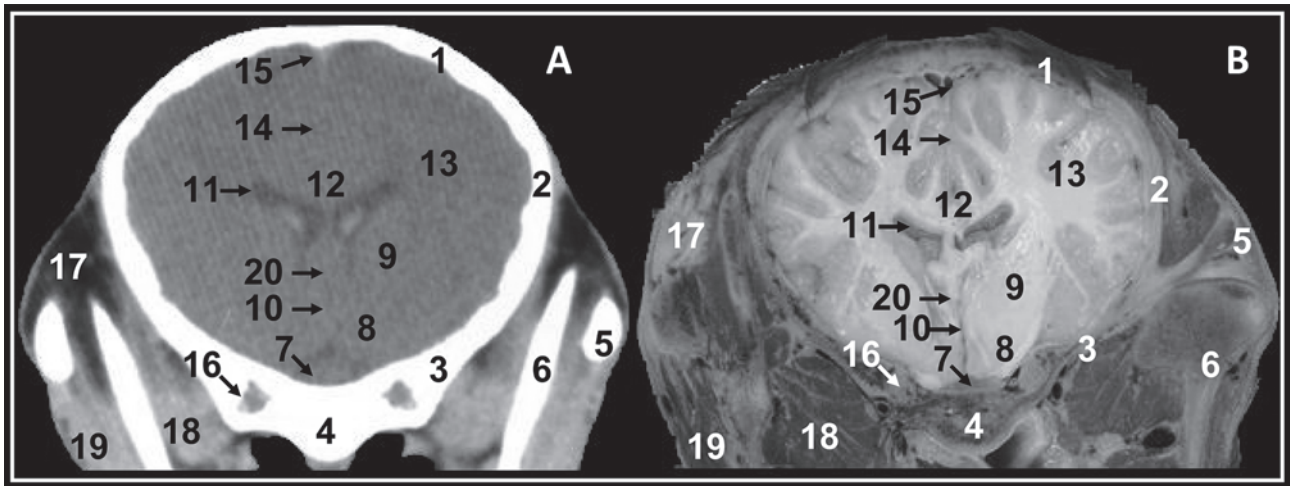
Figure 5. (A) Computed tomography image and (B) anatomic section at the level of hypophysis. 1. Parietal bone; 2. Squamous part of temporal bone; 3. Wing of basisphenoid bone; 4. Body of basisphenoid bone; 5. Zygomatic process of temporal bone; 6. Ramus of mandible; 7. Hypophysis; 8. Hypothalamus; 9. Thalamus; 10. Third ventricle; 11. Lateral ventricle; 12. Corpus callosum; 13. Cerebral hemisphere: temporal lobe; 14. Cerebral longitudinal fissure; 15. Dorsal sagittal sinus; 16. Cavernous sinus; 17. Extraorbital fat; 18. Lateral pterygoid muscle; 19. Masseter muscle; 20. Pineal gland.

(A) Imagen de tomografía computarizada y (B) sección anatómica a nivel de la hipófisis. 1. Hueso parietal; 2. Porción escamosa del hueso temporal; 3. Ala del hueso basiesfenoides; 4. Cuerpo del hueso basiesfenoides; 5. Proceso cigomático del hueso temporal; 6. Rama de la mandíbula; 7. Hipófisis; 8. Hipotálamo; 9. Tálamo; 10. Tercer ventrículo; 11. Ventrículo lateral; 12. Cuerpo calloso; 13. Hemisferio cerebral: lóbulo temporal; 14. Fisura longitudinal del cerebro; 15. Seno sagital dorsal; 16. Seno cavernoso; 17. Grasa extraorbital; 18. Músculo pterigoideo lateral; 19. Músculo masetero; 20. Glándula pineal.
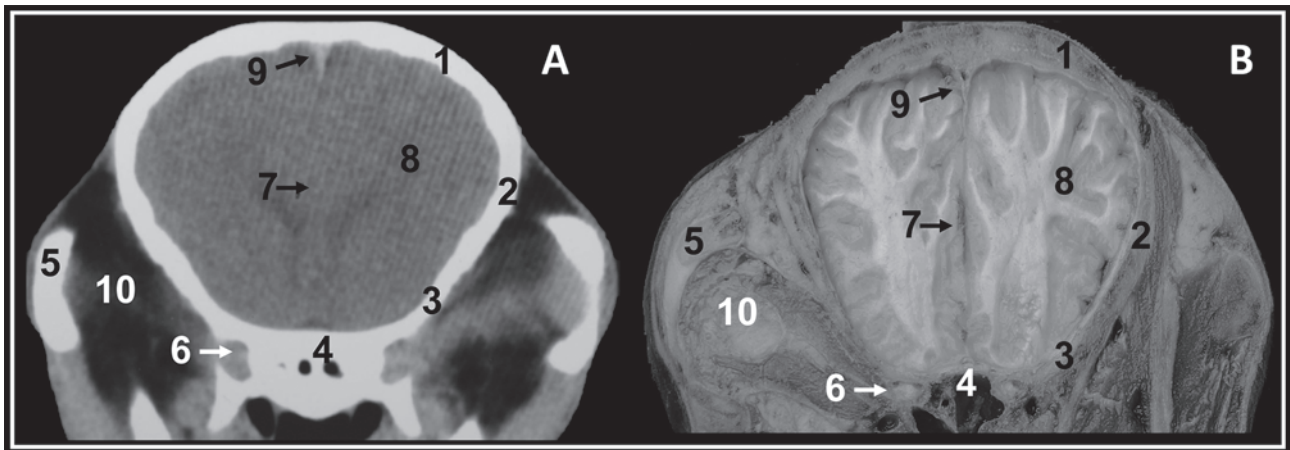

Figure 6. (A) Computed tomography image and (B) anatomic section at the level of sphenoidal sinus. 1. Frontal bone; 2. Squamous part of temporal bone; 3. Wing of presphenoid bone; 4. Body of presphenoid bone; 5. Zygomatic process of frontal bone; 6. Optic nerve; 7. Cerebral longitudinal fissure; 8. Cerebral hemisphere; 9. Dorsal sagittal sinus; 10. Sphenoidal sinus; 11. Intraorbital fat; 12. Extraorbital fat.

(A) Imagen de tomografía computarizada y (B) sección anatómica a nivel del seno esfenoidal. 1. Hueso frontal; 2. Porción escamosa del hueso temporal; 3. Ala del hueso presfenoides; 4. Cuerpo del hueso presfenoides; 5. Proceso cigomático del hueso frontal; 6. Nervio óptico; 7. Fisura longitudinal del cerebro; 8. Hemisferio cerebral; 9. Seno sagital dorsal; 10. Seno esfenoidal; 11. Grasa intraorbital; 12. Grasa extraorbital.

interesting to perform further studies with multidetector CT equipment on live animals and with the administration of contrast medium to establish a protocol for CT angiography.

In conclusion, the anatomical sections were useful tools for a correct morphological and topographic evaluation of the CT images of neonatal foals' brain and associated structures. Findings from this study indicated that CT images resulted in a useful imaging modality for its anatomic evaluation and to aid in the diagnosis by CT of brain disorders of normal neonatal foals.
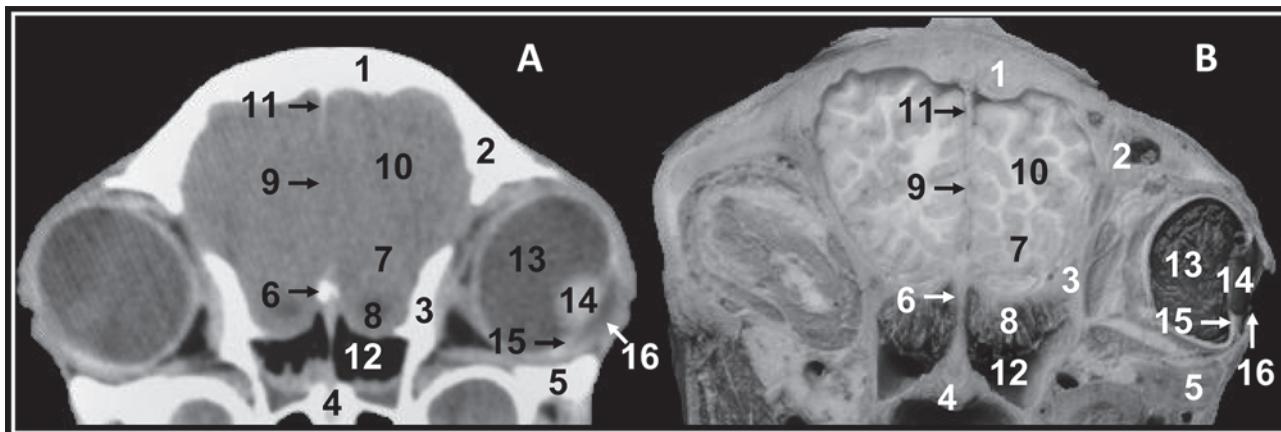
Figure 7. (A) Computed tomography image and (B) anatomic section at the level of ethmoidal labyrinth. 1. Frontal bone; 2. Zygomatic process of frontal bone; 3. Orbital part of frontal bone; 4. Body of presphenoid bone; 5. Temporal process of zygomatic bone; 6. Perpendicular plate of ethmoid bone; 7. Olfactory bulb; 8. Ethmoid labyrinth; 9. Cerebral longitudinal fissure; 10. Cerebral hemisphere: frontal lobe; 11. Falx cerebri; 12. Sphenoidal sinus; 13. Vitreous chamber of eyeball; 14. Lens; 15. Cilliary processes of eyeball; 16. Anterior chamber of the eyeball.

(A) Imagen de tomografía computarizada y (B) sección anatómica a nivel del bulbo olfatorio. 1. Hueso frontal; 2. Proceso cigomático del hueso frontal; 3. Porción orbitaria del hueso frontal; 4. Cuerpo del hueso presfenoides; 5. Proceso temporal del hueso cigomático; 6. Lámina perpendicular del hueso etmoides; 7. Bulbo olfatorio; 8. Laberinto etmoidal; 9. Fisura longitudinal del cerebro; 10. Hemisferio cerebral: lóbulo frontal; 11. Hoz del cerebro; 12. Seno esfenoidal; 13. Cámara vítrea del ojo; 14. Cristalino; 15. Procesos ciliares del ojo; 16. Cámara anterior del ojo.

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