Comparison between ultrasound images of the dog brain with and without the calvaria and its correlation with real anatomy

Comparação entre imagens ultrassonográficas do cérebro do cão com e sem a calota craniana e sua correlação com a anatomia real

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Abstract

Bones are believed to be an effective barrier to obtain sonographic images. In fact, the large difference between acoustic impedances of surfaces of the soft and bone tissues generates significant image artifacts. However, transmission of the ultrasound beam depends on bone thickness and structure. Therefore, the temporal bone has been used as an acoustic window to access the brain of adult patients with ultrasonography. The purpose of this study was to assess the brain of adult dogs using ultrasonography with and without bone interposition, compare the images, and correlate them with the brain anatomy. Ten mesaticephalic adult dogs were used, and the ultrasound examination was performed through the magnum orifice and on the temporal, lateral parietal, and frontal bones. A small craniotomy was performed in the frontal bone for examination without bone interposition. We were able to acquire images of the brain with bone interposition. However, resolution of these images was lower than the ones obtained by craniotomy. Important anatomical structures were identified. Regarding the correlation and the wide availability of ultrasound equipment, it was concluded that ultrasound can be used as a tool for monitoring expansive intracranial lesions or in intraoperative procedures.

Keywords: Ultrassonography. Encephalon. Dogs. Acoustic window.

Resumo

Os ossos são tidos como uma barreira intransponível para obtenção de imagens sonográficas, pois a grande diferença entre as impedâncias acústicas das superfícies de tecidos moles e ósseos gera importantes artefatos de reflexão, contudo, a transmissão do feixe ultrassônico depende da espessura e da estrutura óssea e neste caso o osso temporal tem sido usado como uma janela acústica para o acesso, por ultrassonografia, do encéfalo de pacientes adultos. O presente trabalho examinou o encéfalo de cães adultos com o emprego da ultrassonografia com e sem a interposição do crânio, comparou as imagens obtidas e as correlacionou com a anatomia encefálica. Foram examinados dez cães adultos, mesaticefálicos. O exame ultrassonográfico foi realizado através do orifício magno e dos ossos temporal, parietal (porção lateral) e frontal. No exame sem a interposição óssea foi realizada uma pequena craniotomia no osso frontal. As imagens do encéfalo com a interposição óssea apresentaram resolução inferior as obtidas por craniotomia. Importantes estruturas anatômicas foram identificadas. Devido à correlação e a sua ampla disponibilidade, concluiu-se que o aparelho de ultrassom pode ser usado para o acompanhamento de lesões intracranianas expansivas, bem como em procedimentos intraoperatórios.

Palavras-chave: Ultrassonografia. Encéfalo. Cães. Janela acústica.

Introduction

Ultrasonography (US) of the central nervous system[1] was one of the first applications in the medical field, and several studies have been made with its use in this field, especially in the evaluation of brain changes. However, with the development of computed tomography (CT) in the seventies, use of US in the medical field was almost abandoned and attention of

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physicians was shifted to other diagnostic methods, such as magnetic resonance (MRI). Currently, US remains an excellence method for examination of the brain in pediatric patients, and it is often compared to CT[1,2,3,4]. In these patients, ultrasound examination can be obtained up to about fifteen months of age when the fontanelle, which are used as acoustic windows, are still open. In veterinary medicine, assessment of the ventricles in the diagnosis of hydrocephalus has been the largest application of US in neurology because persistence of open fontanelle in animals with ventriculomegaly is common[5,6,7,8,9,10,11,12,13,14]. In the topography of interthalamic adhesion in dogs, the lateral ventricles are considered increased when they are larger than 0.35 cm in its dorsoventral axis (transversal section) [5,15]. In the veterinary literature, few reports are found on the use of US in the diagnosis of other brain disorders, such as neoplasms[9,12,13,14,16], cysts[17], abscesses[13,18], congenital malformations[20], inflammatory[19], hemorrhagic or ischemic[21,22,23] processes. There are citations on its intraoperative use[13,16,24,25,26] and as a guide for biopsies in the brain[12,27]. In fact, use of US to evaluate the brain of adult animals is restricted due to the presence of skull bones[6,7,11,24]. Some aspects must be considered in the use of transcranial US in adult patients. Especially, there is a concept that bony structures are insurmountable barriers for ultrasound images to be acquired[28]. Really, great differences between the acoustic impedances at the interface of soft-bony tissues generate significant reflection artifacts due to the difference between the velocities of the ultrasound beam in the two media[29,30,31]. Furthermore, absorption of the acoustic beam is also important. In-vitro studies on samples of human cranial bone plate showed that transmission of the acoustic energy through them is variable, depending mainly on their thickness, and the energy transmitted is always less than or equal to 35% of the energy emitted[28]. Transmission of the ultrasound beam also depends on bone structure. A layer of spongy bone (diploe) is found in some skull bones, such as the parietal (dorsal portion) and frontal bones. Such layer contains several bone spicules that vary in shape and direction[32]. These bone spicules are likely to scatter the ultrasound beam and are mainly responsible for its attenuation. On the other hand, the compact bone causes refraction of the ultrasound beam, an effect which is more important than that of attenuation[33]. Due to the acoustic behavior of cranial bones and small thickness of the temporal bone, and regarding that this is a compact bone, it has been used as a window in transcranial US[28,29]. Although CT and MR are expanding diagnostic modalities and their use is becoming increasingly accessible, ultrasound studies through the entire bone plate would be of great value for the diagnosis and follow up of expansive, neoplastic, and hemorrhagic processes because the presence of ultrasound equipment in hospitals is growing, US is fast and less expensive than CT and MR imaging, and they can be performed without administration of anesthesia to the patients. The purpose of this study was to compare images obtained by US of the brain of adult dogs with intact calvaria and those of craniotomized dogs to correlate them with the macroscopic anatomy of the brain of these animals.

Materials and Methods

Ten adult dogs (undefined breed, six males and four females, weight: 15-20 kg) were provided by the Center for Zoonosis Control of Municipality of São Paulo, SP, Brazil, euthanized, and examined immediately. The shape of their skulls was phenotypically classified as mesaticephalic. The brain was evaluated with an ultrasound machine (Philips ATL, HDI-5000, SonoCT, Seattle, Washington, USA) equipped with three multifrequency transducers, one linear (7-12 MHz) and two convex (2-5 and 4-7 MHz) transducers. The brain was evaluated in real-time with a B-mode (brightness mode) ultrasound equipment. The parietal and temporal bones and the foramen magnum were used as acoustic windows for the exam (Figure 1). To access the right and left sides of the animal, it was positioned in the left and right lateral decubiti, respectively. Bilateral trichotomy was performed in the temporal and parietal regions and gel was used as acoustic coupler between the transducer and skin of the animal. From the temporal window, sections were performed in the transverse (rostrocaudal scan) and dorsal (dorsoventral scan) planes. From the foramen magnum, sections were obtained in the sagittal and oblique dorsal planes. In all dogs, it was performed the brain examination through intact frontal bone. After ultrasound brain examination through intact cranial bones, ostectomy was performed on the frontal bone of five of the ten animals (length: ca. 1.5 cm; width: ca. 1.5 cm) caudally to the frontal sinuses, mimicking an open fontanelle. In this region, the skin was folded and then repositioned during examination, and sections in the transverse and sagittal planes were obtained. After US, all (10) heads were frozen and five of them were sectioned dorsally (sagittal and transverse sections in one and four heads, respectively) using an electric band saw. These brains were examined macroscopically and visible changes were not detected in the regions where the sections were made. Anatomical section of the heads in the same planes of the ultrasound sections helped to establish a correlation between the anatomical structures seen by image and macroscopically. Thickness of the parietal (lateral portion) and temporal bones was also measured.

Results

Ultrasonography of the brain through the left and right temporoparietal windows, which was performed with the intact bone plate, allowed visualization of echoic brain tissues, especially the longitudinal fissure, some cerebral sulci, and cerebellar tentorium, which appear as hyperechoic structures (Figures 2A, 3A, and 4). The frontal, parietal, and occipital lobes as well as the diencephalic region were identified according to the topography of sections. Although visualization of the lateral ventricles (anechoic structures) is difficult, they were also identified. Reverberation was a common artifact during this examination. Use of

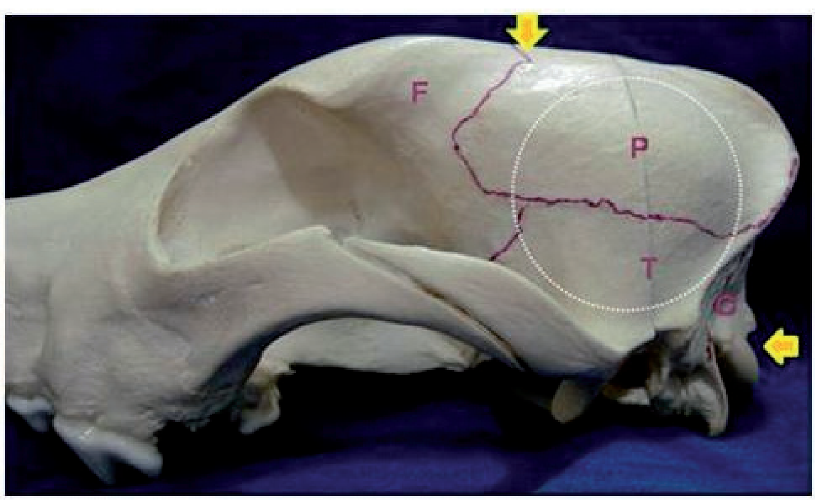

Figure 1 - Lateral view of a dog skull (P: parietal bone; T: temporal bone; F: frontal bone; O: occipital bone). The arrows and dashed circle indicate the regions where the transducer was placed to perform the ultrasound examination of the brain

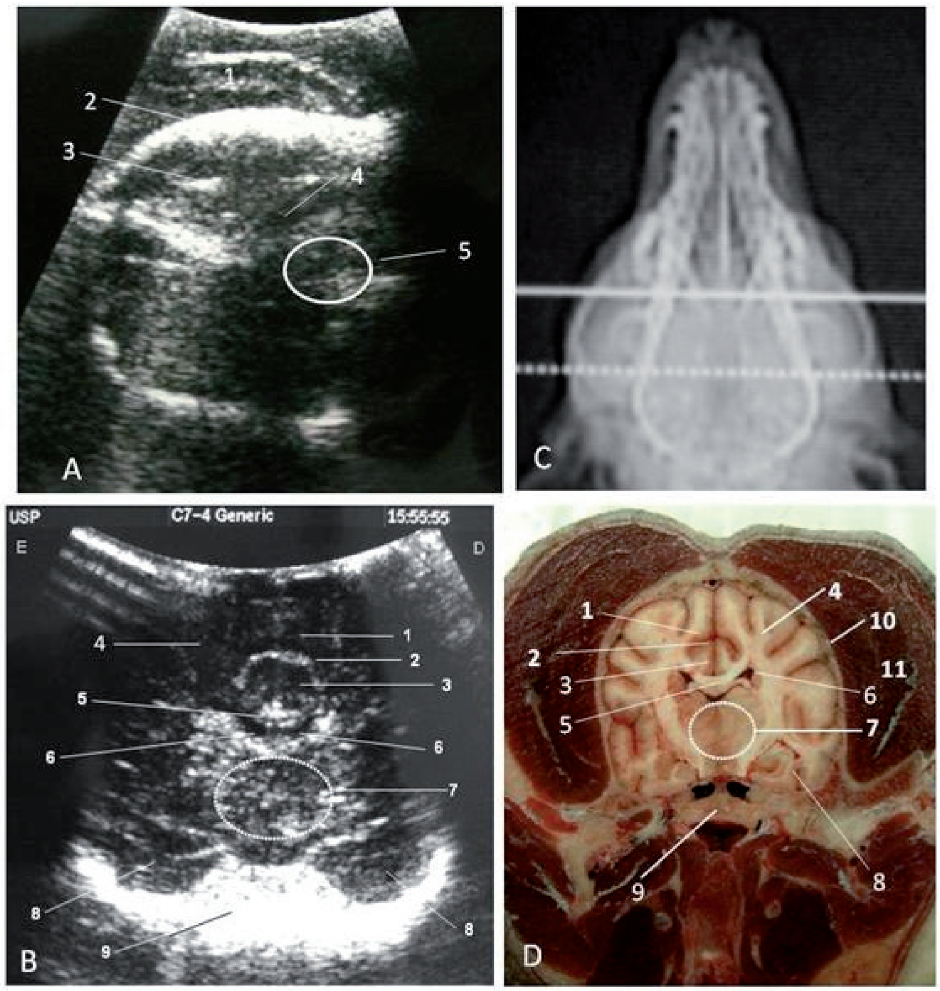

Figure 2 - Dog brain **A**- Ultrasonographic image (transverse plane) obtained through the intact temporal bone (1- temporal muscle; 2- temporal boné; 3- temporal lobe; 4- lateral ventricle; 5- diencephalon). **B**- Ultrasonographic image (transverse plane) obtained from dorsal frontoparietal craniotomy (1- esplenial gyrus; 2- esplenial sulcus; 3- cingulate gyrus; 4- parietal lobe; 5- corpus callosum; 6- lateral ventricle; 7- diencephalon; 8- piriform lobe; 9- basisfenoid bone). **C**- Digital radiography of the head. The dotted line indicates the topography of the section on the images obtained. **D**- Cross section anatomical of the head in the region corresponding to the ultrasound images shown in A and B (1- esplenial gyrus; 2- esplenial sulcus; 3- cingulate gyrus; 4- parietal lobe; 5- corpus callosum; 6- lateral ventricle; 7- diencephalon; 8- piriform lobe; 9- basisfenoid bone; 10- temporal bone; 11- temporalis muscle)

the foramen magnum as acoustic window allowed visualization of the cerebellum, especially the cerebellar vermis, which is characterized by parallel echogenic lines (corresponding to the fissures in this region) (Figure 5B). No image was formed when the frontal and parietal (dorsal region) bones were used as acoustic windows. Ultrasound examination performed through the dorsal frontoparietal craniotomy allowed a better identification of all structures mentioned above, including the choroid plexus (hyperechoic structure inside the lateral ventricle), third and fourth ventricles, corpus callosum (delimited by the hyperechoic sulcus callosum) , medulla oblongata (echoic structure), and sulci (more numerous than those seen through the intact bone) (Figures 2B and 3B).

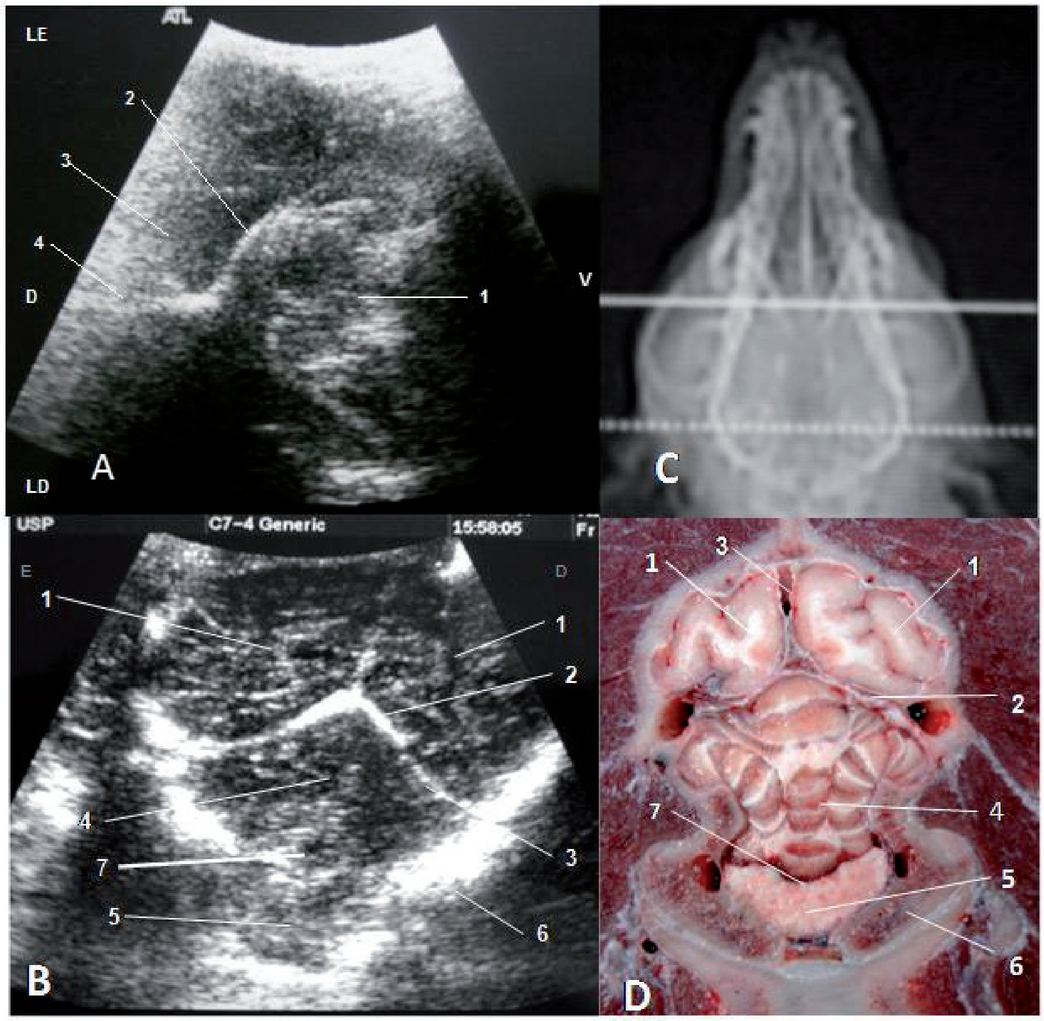

Figura 3 - Dog brain **A**- Ultrasonographic Image (transverse plane) obtained through the intact temporal bone (1- cerebellum; 2- bony tentorium of the cerebellum, 3- left occipital lobe; 4- longitudinal fissure). **B**- Ultrasonographic Image (transverse plane) obtained from dorsal frontoparietal craniotomy (1- occipital lobe; 2- bony tentorium of the cerebellum; 3- membranous tentorium of the cerebellum; 4- cerebellum; 5- medulla oblongata; 6- occipital bone; 7- fourth ventricle). **C**- Digital radiography of the head. **D**- Anatomical cross section of the head in the region corresponding to the ultrasound images shown in A and B (1- occipital lobe; 2- tentorium cerebellum; 3- longitudinal fissure; 4- cerebellum; 5- medulla oblongata; 6- occipital bone; 7- fourth ventricle). The dotted line shows the topography of the section on the images obtained

Discussion

Ultrasonographic images of the dog brain obtained in this study after parietal craniotomy (without interposition of the skull bones) provided a detailed view of it. Ultrasonographic visualization of structures such as the longitudinal fissure, ventricles, choroid plexus, corpus callosum, cerebral gyri and sulci, membranous portion of the cerebellar tentorium, and cerebellum obtained in this study can be considered superior to CT images obtained in other studies. However, this is not a real condition for adult dogs in the clinical routine, because the only acoustic window used in this study mimicked the fontanelle, which closes during the first month of life of these animals. On the other hand, ultrasound may be an

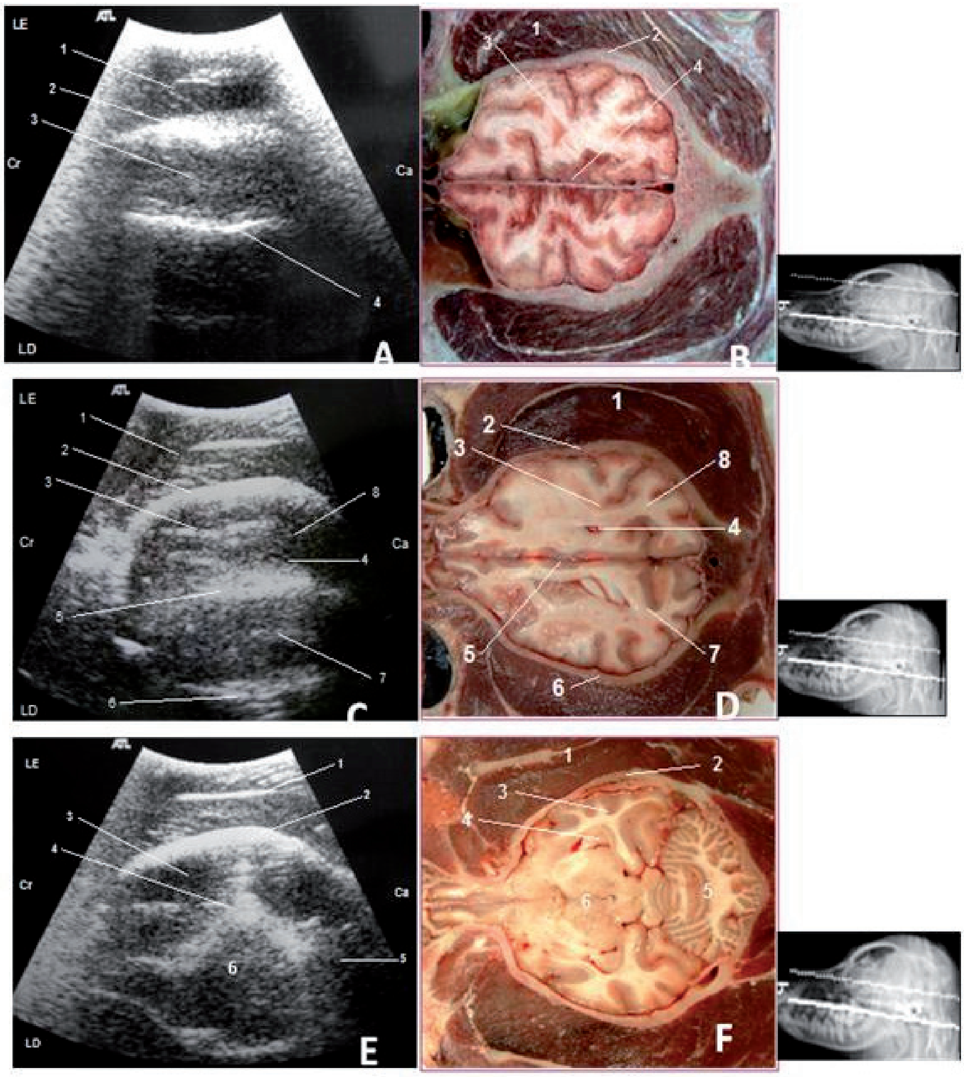

Figure 4 - Dog brain **A** - Ultrasonographic Image (dorsal plane) obtained through the parietal bone (lateral portion) and **B** - anatomical section of the head in the corresponding region (1- temporal muscle; 2- parietal bone; 3- parietal lobe; 4- longitudinal fissure; LE: left side; Cr: cranial, Ca: caudal). **C** - Ultrasonographic Image (dorsal plane) obtained through the temporal bone and **D** - anatomical section of the head in the corresponding region (1- temporal muscle; 2- left temporal bone; 3- sulcus cerebral; 4- lateral ventricle; 5- longitudinal fissure; 6- right temporal bone). **E** - Ultrasonographic Image (dorsal plane) obtained through the temporal bone and **F**- anatomical section of the head in the corresponding region (1- temporalis muscle; 2- temporal bone; 3- temporal lobe; 4- hippocampus; 5- cerebellum; 6- diencephalon). The dotted line in the digital radiographs alongside corresponds to the region of the sections

excellent tool for intraoperative use in craniotomy and trepanation, mainly helping to localize injury and vascularization, reducing both damage to normal brain tissue and surgical time[12,13,16,24,25,26,27]. Ultrasound examination of the brain using the foramen magnum as acoustic window allowed a restricted evaluation of the brain, although without bone interposition. Only the cerebellum, especially the vermis with its multifissured aspect, was identified in the images of dogs examined in this study.

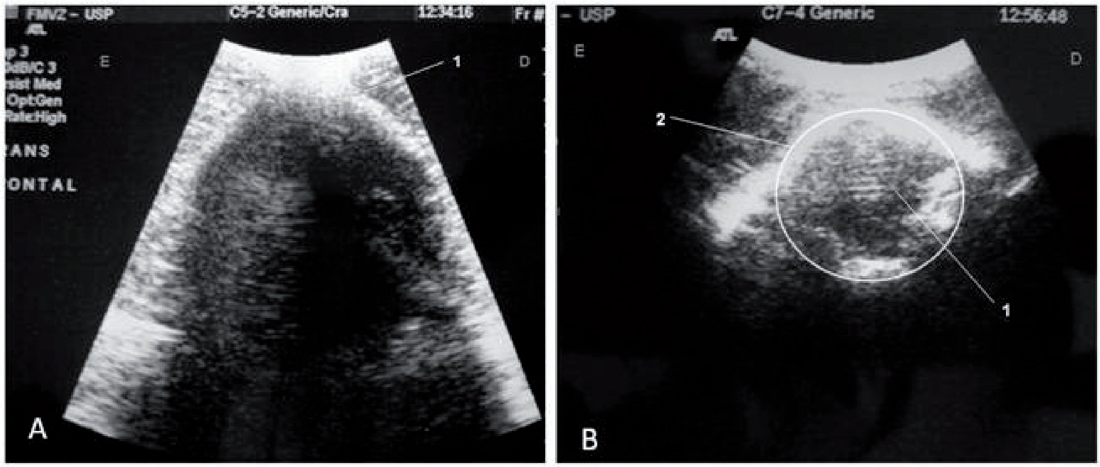

Figure 5 - Dog brain **A** - Ultrasound examination (transverse plane) performed through the intact frontal bone (1- frontal bone). The image was not formed. **B** - Ultrasonographic image (oblique dorsal plane) obtained through the foramen magnum (1- cerebellum; 2- foramen magnum)

In Veterinary Medicine, several authors state that use of transcranial ultrasound in adult animals is not possible. They admit that skull bones cause 100% reflection of ultrasonic waves, preventing formation of images[6,7,11,24]. In this study, image formation was also not observed when the transducer was positioned on either the frontal bone or the dorsal frontoparietal transition. However, images of the brain were obtained when the transducer was placed on either the temporal bone or the lateral portion of the parietal bone of the ten dogs examined in the present study. As the temporal (squamous portion) and parietal (lateral portion) bones have compact structure and small thickness (0.15-0.20 and 0.30-0.35 cm, respectively), they can also be used as acoustic windows to perform ultrasound examinations in dogs. The physical explanation for the acoustic behavior of skull bones in man as proposed by White, Curry, and Stevenson[33] can be applied to the dog.

Important structures could be visualized in the examination through the bone, although resolution of images thus obtained is lower than that obtained in the examination without interposition of the bone. Several factors can be pointed out to explain the decrease in image quality. Firstly, transmission of acoustic energy through a bone structure is always less than 35% of the emitted energy. In addition, the large difference between the values for acoustic impedance of surfaces of soft and bone tissues generates significant artifacts. In order to make a good scan of the brain, examining both right and left sides is necessary because reverberation artifacts make it difficult to assess the side contralateral to the side under examination. Thus, use of low-frequency (2-5 MHz) transducers is recommended. Regarding resolution, ultrasound images were markedly improved by the technology of multifrequency transducers. In addition, use of a single transducer provides additional flexibility. In this study a convex transducer was used. However, we believe that a transducer microconvex is the most appropriate due to the small area of contact with the surface to be examined.

Although brain lesions were not evaluated in this study, the literature shows that neoplastic[9,12,13,16,25,28], infectious[18], hemorrhagic[1,2,3,4,21], and cystic[17] processes can alter the normal echogenicity of brain tissue and thus they could be detected by ultrasound examination depending on their size and location. In addition, shift of the longitudinal fissure, a hyperechoic line clearly visible in our sample of dogs, could be an indicator of the mass effect caused by expansive intracranial lesions. However, we emphasize herein the difference between sonographic images obtained with and without the bone interposition, in which the former have a significant loss of quality by the physical reasons discussed above. Thus, sonographic examinations, in which alterations are absent, presence of brain disease cannot be ruled out. This study did not include examination of brain vasculature because dog carcasses were used. It is known that Doppler ultrasound can identify blood vessels in the region studied[22,23,34].

Conclusions

The authors of this study did not intend to state that US is a substitute for established methods, such as CT and MRI, to examine the brain of adult dogs. But, it was presented its possibilities and limitations and consider its use for this purpose. Sonographic images of the brain were obtained through the intact temporal and parietal (lateral portion) bones in the dogs studied in which anatomical regions were identified, although its resolution is lower than that of images obtained without bone interposition. It is important to remember that some of the structures mentioned above may not be identified in different section planes due to variations that exist in different constitutional (brachycephalic, mesaticephalic, dolicocephalic) types. Moreover, as it occurs in ultrasound examination of soft tissues, identification of structures examined through bones also depend on professional experience. Furthermore, thickness of the temporal (squamous portion) and parietal bones in the same animal is not uniform. The very imprint of the cerebral gyri on the internal surface of the calvaria displays this irregular aspect. This study contributes with the observation of some aspects of anatomical normality in dogs. However, further studies with live animals are necessary to assess the method sensitivity in the ultrasound investigation of brain alterations through the cranial bones.

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