Methodological standards for Transcranial Sonography of brain parenchyma

Padrões metodológicos para a Ultrassonografia Transcraniana do parênquima cerebral

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ABSTRACT

Background This paper is the first in a series of narrative reviews highlighting the advancements in diverse applications of ultrasonography in Neurology. Neurological sonography is a cost-effective and safe neuroimaging method with expanding applications. Transcranial sonography (TCS) investigates the brain parenchyma with B-mode sonography insonating through the temporal bone windows with a 1-5 MHz transducer. It may assist in the differential diagnosis of movement disorders and, especially, of Parkinson's disease. More recently, a good correlation to MRI (Magnetic Resonance Imaging) in Alzheimer's dementia diagnosis was found.
Objectives In the present paper we review the standardized method of transcranial sonography for B-mode (bidimensional) imaging of the brain parenchyma in movement disorders and other neurodegenerative conditions.
Methods The authors used their experience with the method and reviewed the updated literature on the technique of TCS in the evaluation of brain parenchyma structures that are helpful in the diagnosis of neurological intracranial conditions.
Results The structures that can be visualized and measured at four axial planes - mesencephalic, thalamic, ventricular bodies (*cella media*) and posterior fossa - and at a coronal plane - medial temporal lobe structures - are described.
Conclusions Although ultrasonography is named an "operator-dependent" technique, this can be overcome by increasing standardization of the exam, sophistication of equipment software and by expanding expertise among specialists.

Keywords Neuroimaging; Transcranial Doppler Ultrasonography; Brain; Diagnostic imaging

RESUMO

Fundamento O presente artigo é o primeiro de uma série de revisões narrativas destacando os avanços em diversas aplicações da ultrassonografia em Neurologia. A ultrassonografia neurológica é um método de neuroimagem econômico e seguro com aplicações em expansão. A Ultrassonografia Transcraniana (UTC) investiga o parênquima cerebral com ultrassonografia modo B insonando através das janelas ósseas temporais com transdutor de 1-5MHz. O exame pode auxiliar no diagnóstico diferencial de distúrbios do movimento, principalmente da doença de Parkinson. Mais recentemente foi encontrada uma boa correlação com a Ressonância Magnética no diagnóstico da demência de Alzheimer.
Objetivos No presente artigo nós revisamos o método padronizado de realização da UTC para a aquisição de imagens no modo B (bidimensional) do parênquima cerebral em transtornos do movimento e outras doenças neurodegenerativas.
Métodos Os autores utilizaram a sua experiência com o método e revisaram a literatura atualizada sobre a técnica da UTC na avaliação de estruturas do parênquima cerebral que são úteis no diagnóstico de condições neurológicas intracranianas.
Resultados São descritas as estruturas que podem ser visualizadas e medidas em quatro planos axiais - cortes mesencefálico, talâmico, corpos ventriculares (cella media) e fossa posterior - e em plano coronal - estruturas mediais do lobo temporal.
Conclusões Embora a ultrassonografia seja denominada técnica "operador-dependente", isso pode ser superado com o aumento da padronização do exame, com a sofisticação dos softwares dos equipamentos e com a ampliação da expertise dos especialistas**.**

Palavras-chave Neuroimagem; Ultrassonografia Doppler Transcraniana; Diagnóstico por imagem; Doenças do Sistema Nervoso Central; Transtornos do movimento

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INTRODUCTION

The year was 1995: in a seminal study, Dr. Becker (1961-2003) and collaborators demonstrated the utility of transcranial ultrasound in identifying and evaluating the substantia nigra in patients with Parkinson's disease (PD) [1]. This groundbreaking work opened a new horizon for Neurosonology.

Today, 30 years later, ultrasonography (US) has emerged as a versatile tool, offering unique insights into the intricate architecture of the brain and peripheral nervous structures. From assessing cerebral blood flow with Transcranial Doppler (TCD) to detecting subtle structural abnormalities with B-mode (bidimensional) parenchyma evaluation (also known as Transcranial Sonography - TCS), US provides neurologists with self-performing, real-time, non-invasive views of the brain's anatomy and function. This ability is particularly valuable in critical care settings where rapid assessments are crucial [2].

In the field of neuromuscular diseases, the fast evaluation of muscles and peripheral nerves with High-Resolution Ultrasonography may add important clues to the identification of the disease process. For example, the ability to differentiate a demyelinating from an axonal neuropathy was revealed by several studies on chronic inflammatory demyelinating neuropathy, among other diseases [3]. It is also worth emphasizing US usefulness in guiding neurological procedures such as botulinum toxin injections [4], lumbar punctures, muscular biopsies etc.

US is currently being utilized as an extension of the armed neurological physical examination integrated into a diagnostic pipeline, in line with what occurs in other areas, such as Intensive Care. Furthermore, in research settings, this method has been investigated as an imaging biomarker with potential applicability in diagnostic and prognostic predictive models.

Despite decades of use and demonstrated utility in various conditions, both in central and peripheral nervous systems, Neurosonology is still unknown to many neurologists. Scientific advancements support TCS use in certain areas, particularly in the diagnosis of Parkinson's disease and other movement disorders. However, the scarcity of robust studies across diverse conditions precludes definitive assertions regarding the utility or futility of the examination in different scenarios, composing instead a mosaic of uncertainties regarding its diagnostic, prognostic, biomarker, and procedural assistance roles.

Notwithstanding these gaps, the method is harmless, is quick to perform at low cost and demands no sedation. The advantages of ultrasound over other neuroimaging modalities are notable. In terms of accessibility and cost-effectiveness, US stands out positively, making it safe for repeated assessments and suitable for sensitive patients such as pregnant women and children, those with chronic renal disease, with cardiac pacemakers, with deep brain stimulation electrodes, claustrophobic, etc. Due to its real-time imaging nature, it is less susceptible to motion artifacts, which is advantageous in patients with movement disorders as examiners can manually compensate for involuntary movements.

In summary, the US has evolved into a pivotal tool in Neurology, bridging diagnostic, prognostic, and procedural applications across a wide range of neurological disorders. Its real-time imaging capability, cost-effectiveness, safety profile, and accessibility make it a valuable complement to other neuroimaging techniques. Despite the gaps in robust evidence for some conditions, these uncertainties serve as opportunities for further investigation and innovation. Over the course of these 30 years of research, the method has been studied in numerous countries around the world, including Brazil [5-12].

As part of their continued efforts to advance knowledge in the field, the authors are introducing a series of articles focused on the diverse applications of US in Neurology, both for diagnostic purposes and to assist in various procedures such as: differential diagnosis of Parkinson´s disease, midline shift evaluation in neurocritical care, ultrasound-guided application of botulinum toxin in dystonia, differential diagnosis in peripheral nerve disease, etc. This series is designed to explore the most recent advancements in Neurosonology, highlighting cutting-edge research and innovations that are shaping the field. It includes the following topics: Transcranial brain parenchyma sonography in movement disorders and other neurodegenerative diseases, Ultrasound-guided botulinum toxin injection in cervical dystonia, Transcranial Doppler in neurocritical care, Transcranial brain sonography in neuropsychiatric diseases and High-resolution Ultrasound in peripheral nerve disease. Our objectives are to consolidate the latest evidence and encourage new research in this field as well as to call the attention of clinical neurologists to the usefulness of the technique to their daily work.

In the present paper we review the method of transcranial sonography for B-mode imaging of brain parenchyma.

METHODS

The authors used their theoretical and practical experience with the method, which dates back to 2010 in the Doctoral Thesis of RCLF carried out under the supervision of Prof. Daniela Berg at the University of Tübingen, Germany, through the CAPES sandwich-doctorate scholarship. The literature on the technique procedures of TCS was reviewed for the evaluation of brain parenchyma structures that are helpful in the diagnosis of neurological intracranial conditions. The terms Diagnostic Sonography, Transcranial Sonography, Parkinson´s disease, Atypical parkinsonisms and Alzheimer´s dementia were used in the

databases of BIREME, PubMed and Lilacs. The results were organized in the items of (1) Equipment and general procedures of standard transcranial sonography examination; (2) Neuroanatomy in B-mode sonography - axial planes and (3) Neuroanatomy in B-mode sonography - coronal plane.

RESULTS

1. Equipment and general procedures of Standard Transcranial Sonography Examination

Neurological sonography has been investigated In many scenarios since the first description of the acquisition of cerebral blood flow patterns in the basal arteries using transcranial Doppler by Aaslid and cols[13]. The technological advances of the technique allowed, in 1995, the german neurosurgeons Georg Becker and cols.[1] to describe, for the first time, an alteration visualized in the brain parenchyma through sonography in Parkinson's disease (PD) patients.

The method depicts echogenic deep brain structures with good resolution and has important advantages. First, ultrasound equipment is widely available in health facilities where the same transducers are already used to perform echocardiograms. As TCS is based on different physical principles - reflexion of ultrasonic waves - than are other imaging techniques, it can offer unique and complementary information on brain tissue pathology. Moreover, bedside exams are a possibility. Importantly, ultrasound only requires a short examination time, circa 30 minutes, and can be used in patients with involuntary movements, because the investigator is able to compensate for the patient's movements[9,14]. The interobserver variability of the method is low in the hands of experienced investigators[19].

Despite all its advantages, TCS presents a methodological challenge in the transmission of ultrasonic waves through the thin, scaly portion of the temporal bone known as the temporal window. In some patients, this temporal osseous window is inadequate for the transmission of ultrasonic waves, which hinders the formation of the image. This phenomenon can occur in 10-40% of certain populations, especially elderly oriental women[20,21] . A Brazilian study from our group in UFRJ found a 10.8% of inadequate bone windows, suggesting that a large proportion of Brazilians would be eligible for TCS as, for example, the European population is [5]. Unfortunately, for 10.8% of individuals with an inadequate bone window, the exam cannot be performed. Another Brazilian study found that the radiologic findings on computed tomography of the skull that were independent predictors of inadequate bone windows were pneumatized temporal bone and temporal bone thickness [20].

An optimized ultrasound system equipped with a 1-5 MHz phased-array transducer should be used. This type of transducer is already used to obtain echocardiograms and the preset of Transcranial Doppler is available on all modern equipment.

The exam is performed with the patient lying supine and the probe (or transducer) placed at the squamous part of the temporal bone just in front of the ear, in parallel to the orbito-meatal line (Fig. 1-A).The ultrasound waves pass through this region, where the temporal bone is thinner and allows sound waves of low frequency to penetrate the skull and to reach the deep brain structures. The investigator must look for the best window, i.e. from where the best image can be generated - gently moving the probe anterior, superior or posteriorly as shown in the illustrative drawing in Fig. 1-A. Once the best window is found, the transducer should no longer be moved. All insonation planes are obtained just by angulating the transducer from there (Fig. 1-B).

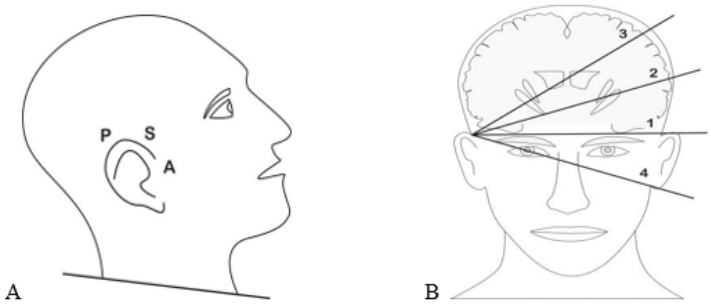

Figure 1 - Bone windows and insonation planes for performing transcranial ultrasound examination (TCS). A) Temporal bone windows: (A) anterior, (S) superior and (P) posterior. B) Axial insonation planes: 1-mesencephalic, 2-thalamic, 3-cella media, 4-posterior fossa.

Table 1 summarizes standard system settings that can be individually adapted. A penetration depth of 14-16 cm allows for visualization of the brain parenchyma up to the contralateral skull bone (Fig. 2-A).

Table 1 - Ultrasound system settings for Transcranial Sonography

Parameter	Settings	Key
Menu	Vascular > TCD	Preset
Penetration depth	Begin with 14-16cm; see contralateral bone	Depth
Dynamic range	45-50dB (axial planes); 110dB (coronal plane)	Dynamic range
Contour amplification	Moderate to high	Smooth
Image brightness	Adjust manually, not too high - image more black than white	Brightness
Transducer frequency	1.0 to 5.0 MHz - preferably 2.0 to 3.0 MHz	THI
Tranducer type	Sectorial	Probe

TCD - transcranial Doppler; dB - decibels; MHz - mega Hertz

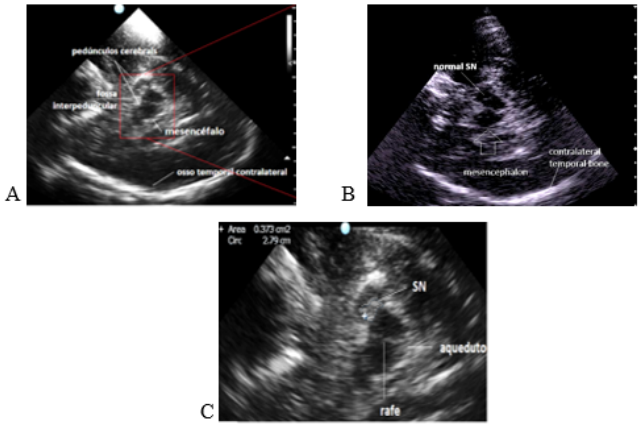

Figure 2 - Evaluation of the substantia nigra (SN) at the mesencephalic plane in transcranial sonography. A) At the center of the image lies the butterfly-shaped mesencephalon (mesencéfalo), which is hypoechoic relative to the surrounding basal cisterns. In the ipsilateral cerebral peduncle (top of the image - pedúnculos cerebrais), one can recognize an echogenic area on the SN locus. The contralateral temporal bone is depicted at the bottom of the image as a highly echogenic semicircle (osso temporal contralateral). The red box indicates the area that will be zoomed (shown in image B). B) Enlarged image to measure the SN echogenic area of a Parkinson's disease patient, which was 0.37 cm² (reference value: N<0.23 cm²). This echosignal is called hyperechogenic SN or SN+. The Sylvian cerebral aqueduct is seen dorsally (aqueduto) as two thin parallel lines and the midline raphe (rafe) is found as an echogenic line in the middle of the mesencephalon running a frontal-dorsal direction. C- Normal SN of a healthy subject.

TCS allows for the identification of various structures within the brain parenchyma in standardized axial and coronal planes [17,18]. Their location and echogenicity enable the correct recognition. A structure is considered hyperechoic when it is more echogenic i.e. has higher brightness, more white, than the surrounding tissue, used as a reference. The highest echogenicity of the calvarial bones, specifically the temporal bones, permits their immediate recognition at the periphery of the ultrasound image (Fig. 2-A). Other highly echogenic structures are the tiny ventricles walls, the basal cisterns and the cortical sulci. Normal neural tissue is usually hypoechogenic as one can appreciate looking at the normal butterfly-shaped mesencephalon (Fig. 2).

2. Neuroanatomy in B-mode sonography - axial planes

Mesencephalic plane - the first to be evaluated

The axial plane through the mesencephalic brainstem is the referential one, from which other planes would be looked for, just angulating up and down the probe. The plane is acquired by insonation parallel to the imaginary orbitomeatal line (Fig. 1-B); it depicts the hypoechoic mesencephalon at the center of the image surrounded by the echogenic basal cisterns (Fig. 2-A). The substantia nigra (SN) is evaluated in the ipsilateral peduncle as a thin, sometimes dotted ribbon. Some other structures can be seen, such as the brainstem midline raphe and the Sylvian aqueduct dorsally.

The normal SN has identical hypoechogenicity to the mesencephalon and is barely distinguished Fig 2-C). Each SN should be evaluated from the ipsilateral insonation side. The categorization of the SN as hyperechogenic suggests a pathological process. The echogenicity of the SN used to be graded semiquantitatively as isoechogenic, mildly echogenic and hyperechogenic regarding the surrounding mesencephalon. In contrast to this subjective evaluation, the planimetrically measured area of nigral echogenicity has proven to be better for comparison across observers and studies, thus enhancing the reproducibility of the method. (Fig. 2-B) [14,19]. In general, SN echogenic areas above 0.20-0,25cm² are considered enlarged and probably pathogenic [22]. Among different laboratories and equipment, the cut-off for the SN categorization as pathological lies between 0.20 to 0.25 cm². The largest SN should be considered to establish a diagnosis. In our laboratory at the HUCFF-UFRJ we defined a cut-off at >0.23cm² for the largest SN for a sensitivity of 83% and a 89.9% specificity to suggest PD with the exam [23]. Table 2 summarizes normal values and characteristics of cerebral structures depicted by TCS.

The cause of SN hyperechogenicity is only partially understood. Animal models and pathology studies suggest an association between iron content and the higher echogenic signals [22]. The relevance of heavy metal accumulation for SN echogenicity is further underlined by the finding that SN and basal ganglia hyperechogenicity have been reported in several brain disorders with heavy metal accumulation including iron and copper [24,25].

Just below and medially to the SN image we can sometimes find a round structure slightly echogenic, half the SN large, corresponding to the red nucleus. It is not always easy to detect it, but one should not include its size in the SN measure.

The brainstem raphe can be visualized as a thin echogenic line splitting the mesencephalon in two equal parts (Fig. 2-B). The normal state of the raphe is characterized by a signal intensity similar to that of basal cisterns and a continuous representation without interruptions. The presence of abnormal echogenicity is classified when interruptions or absence of the raphe occur from both sides of insonation. This classification can be done using an easy 2-point system, where grade 0 indicates the invisibility of the raphe or an interrupted one, whereas grade 1 represents an echogenic continuous normal raphe. The raphe categorization in grade 0 is found mostly in depressive states [26]. The mesencephalic area is obtained by encircling the whole mesencephalon. Some authors argue that measuring the ipsilateral peduncle and multiplying it by two offers more reliable mesencephalic area evaluation [17,23].

Thalamic plane

By tilting the probe 10-20º upward without moving it away from the bone window, we find the thalamus plane where the two hyperechoic parallel lines of 3rd ventricle walls (ependyma) lie in the midline at a depth of 6-8 cm. The 3rd ventricle is surrounded by the two thalamic ovoid hypoechoic structures (Fig. 3 - A). A highly echogenic

structure lies dorsal to the ventricle, corresponding to the calcified pineal gland, a landmark of this plane. Here we can also find the lentiform nucleus which is situated more frontal and lateral to the thalamus and the caudate nucleus behind the frontal horns of the lateral ventricle. In normal situations it is very difficult to discern these nuclei as they all have the same low echogenicity. However, in pathological situations, the higher echogenicity of lentiform nucleus or of caudate nucleus may point to a specific disease as atypical parkinsonism or Huntington's disease, respectively [9,11,27].

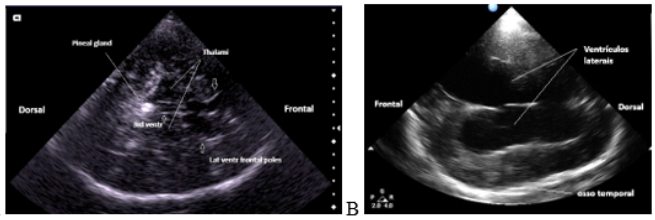

Figure 3 - Transcranial ultrasound images. A) Thalamic plane. A highly echogenic structure lies dorsally in the middle of the image and represents the pineal gland; in front of it, lie the parallel walls of the 3rd ventricle delineating the anechoic space of cerebrospinal fluid. Frontal to it, the two anechoic comma-shaped frontal horns of lateral ventricles are found. On each side, lateral to the 3rd ventricle, the two thalamic hypoechoic ovoid nuclei can be observed. Usually, the lentiform and caudate nucleus cannot be visualized distinctly from the thalamus. B) Cella media plane in a patient with hydrocephalus. Equidistant from the midline we can observe two oval anechoic images corresponding to the bodies of the lateral ventricles.

Cerebral ventricles are measured in this plane from the lines that delineate their anechoic liquoric space. The 3rd ventricle measures about 0.5-0.7cm width in healthy young people and reaches a maximum width of 1.0 cm in > 60 years old. Studies have shown excellent correlation between measures obtained by TCS and those obtained by MRI for 3rd ventricle diameter[5]. The contralateral frontal horn of the lateral ventricle is also visualized in thalamic plane by tilting the frontal part of the probe a little bit cranially to reach the comma-shaped anechoic space (Fig. 3-A) The normal lateral ventricles measure <1.7cm in young people and <2.0cm in the older [14,28,29].

Cella media plane

A further upward inclination of 20º - 30º of the probe from the thalamic plane leads to the plane of the lateral ventricles bodies that appear as paired elongated oval anechoic areas (Fig. 3-B). The contralateral one should be measured. It is important to note that lateral ventricle dimensions obtained in MRI or CT should not be directly compared to TCS measurements because TCS generates somewhat oblique images. Nonetheless, some studies have shown good intraobserver (r = 0.90) and interobserver (r = 0.87) agreements in assessing the lateral ventricular width in TCS [29]. Normal values are the same as that for frontal horns: up to 1.7cm in young people and up to 2.0cm in people older than 60 years.

Posterior fossa plane

The posterior fossa's plane can be seen as one rotates the probe about 30-45° from the mesencephalic plane [6,17,21]. This plane allows for the evaluation of the cerebellar hemispheres with their typical appearance of alternating bright and dark lines (Fig. 4-A). The 4th ventricle can be visualized as well, especially if it is enlarged. Fourth ventricle enlargement of >1.0cm occurs in cerebellar atrophy or in hydrocephalus (Fig. 4-B). It is helpful in the differential diagnosis of atypical Parkinsonisms, as multiple system atrophy [30] . The visualization of this plane is difficult and depends on the individual acoustic window width, being achieved adequately in only about 30-40% of the exams.

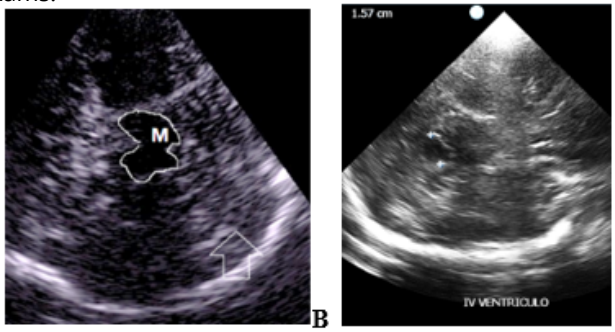

Figure 4 - Transcranial ultrasound images. A) Posterior fossa plane depicting cerebellar folia to the right of the image (open arrow). IV ventricle is not seen and is probably of normal size. B) Posterior fossa plane (left side of the image) depicting an enlarged fourth ventricle behind the brainstem in this patient with cerebellar atrophy (measures 1.57cm).

3. Neuroanatomy in B-mode sonography - coronal plane

This plane is useful for the evaluation of medial structures of the temporal lobe (hippocampus, parahippocampal and entorhinal cortex). It is acquired from the plane of the third ventricle by rotating the probe 90° and positioning it perpendicular to the orbitomeatal line. The dynamic range has to be adjusted to 110 dB (Table 1). At a depth of approximately 5 cm, on the upper part of the image, it is possible to identify a hook-shaped white structure composed by the hyperechoic choroid plexus in the choroidal fissure encircling the medial temporal lobe, which appears with a gray tone (Fig. 5-A). The obtained images should be frozen and magnified 4-5 times for measurement purposes. Measures that may be useful are the temporal lobe structures height (H), choroidal fissure height (CF) and temporal pole of lateral ventricle width (TPv) [18] (Fig. 5-B).

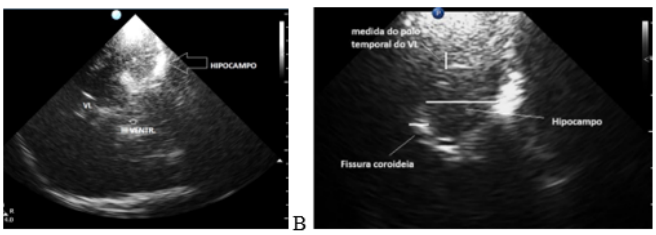

Figure 5 - Transcranial sonography at the coronal plane. A) Hook-shaped echogenic image of choroidal fissure around temporal lobe structures (open arrow - hipocampo). At the center of the image the 3rd ventricle is seen. B) Enlarged image showing two measurements: temporal pole of lateral ventricle width (upper vertical trace), medial temporal lobe structures height (middle horizontal trace) and choroidal fissure height (lower horizontal trace).

As far as we know, there is only one published research validating these measurements. In 2020, Yilmaz and cols.[18] evidenced good agreement between TCS and MRI. The classification of medial temporal lobe atrophy with MRI for diagnosing Alzheimer's disease, called the MTA (medial temporal lobe atrophy) score was compared to a score created by the authors, named the MTA score in TCS (MTA-S or medial temporal lobe atrophy - sonography). This was defined as the sum of CF with TPv (MTA-S=CF+TPv). It is important to note that the MTA score of MRI is qualitative while the MTA-S score proposed is quantitative. So, as the hippocampal structures atrophy, the score on TCS tends to increase. Yilmaz and cols.[18] showed that MTA-S scores below 0.6cm correspond to a MTA score of 0 or 1 in MRI (without atrophy); MTA-S values between 0.84cm and 1.0cm indicate mild to moderate hippocampal atrophy, corresponding to MTA scores 2 to 4 (Table 2). The score should be calculated for each hippocampal structure, right and left, acquired by insonating from each side of the temporal window.

Table 2 - Normal values and characteristics of cerebral structures depicted by Transcranial Sonography

Structure	Plane	Site	Normal value *
SN echogenic area	Axial - Mesencephalic - orbitomeatal line	Ipsilateral	< 0.20-0.25 cm²
Mesencephalic area	Axial - Mesencephalic - orbitomeatal line	Midline	≥ 4,0 cm²
3rd ventricle	Axial inclined - thalamic	Midline	young ≤ 0.7 cm; older than 60y ≤ 1.0 cm
Lateral ventricle frontal pole	Axial inclined - thalamic	Contralateral	young ≤ 1.7 cm; older than 60y ≤ 2.0 cm
Lateral ventricle body	Axial inclined - cella media	Contralateral	young ≤ 1.7 cm; older than 60y ≤ 2.0 cm
4th ventricle	Oblique - posterior fossa	Midline	< 1.0 cm
MTA-S (CF + LPv)	Coronal - hippocampus	Ipsilateral	≤ 0.84 cm
VES-S (3rd+TPvRight+TPvLeft)	Axial - thalamic and coronal - hippocampus	Midline and ispsilateral	≤ 1.5 cm
RI – MCA	Axial - Mesencephalic - orbitomeatal line	Ipsilateral	≤ 0.6
PI – MCA	Axial - Mesencephalic - orbitomeatal line	Ipsilateral	≤ 1.04
			Semiquantitative score
Brainstem raphe	Axial - Mesencephalic - orbitomeatal line	Midline	0 = invisible, hiphoecoic or interrupted (pathological raphe);1 = hyperechoic, continuous (normal raphe)

* According to most authors from different laboratories and equipments [23].
CF- choroidal fissure; LV - lateral ventricle; MCA- medium cerebral artery; PI - pulsatility index; RI - resistive index; SN- mesencephalic substantia nigra; TPv- temporal pole of lateral ventricle
VES-S - ventricular enlargement score - sonography

The second score to be used was created by the same authors and has no correspondence to a score obtained with MRI [18]. It is composed of the sum of the 3rd ventricle measured at the thalamic axial plane (Fig. 3) with both temporal poles of lateral ventricles (TPv), visualized in the coronal plane by insonation on each side of the head. This was called the ventricle enlargement score in sonography or VES-S (VES-S=3rd+TPvRight+TPvLeft). This score roughly correlates with the loss of brain parenchyma - the smaller the brain mass, the larger the ventricles (Table 2).

Yilmaz and cols.[18] demonstrated that cut-off values of MTA-S >0.84cm and VES-S >1.5cm correctly identify 84% of patients with Alzheimer's disease in relation to healthy controls of similar age and correctly rule out a dementia diagnosis in 93% of individuals who scored below these values. Additional studies are highly desirable to establish definitely the value of these hippocampal measurements performed by TCS in neurological practice to diagnose or to monitor dementia.

Future perspectives

Future perspectives in TCS examination for movement disorders and other neurodegenerative diseases are promising, driven by advancements in device sophistication. Research focusing on the standardization of some measurements is urgently necessary, such as measuring the mesencephalic area to improve accuracy in the differential diagnosis of Parkinson´s disease and Progressive Supranuclear Palsy or hippocampal measurements to diagnose dementia, etc. New technologies for evaluating the echogenicity of structures, such as quantifying the tone of the pixels in the digitized image, can bring advances in the method's performance and increase its diagnostic accuracy. In the next few years, we can foresee an exceptional evolution of the technique secondary to the technological advances of the digital era.

CONCLUSIONS

TCS depicts cerebral structures accurately and safely. Increased equipment portability allows bedside evaluation and circumvents the acquisition challenges present in many MRI and CT machines, such as weight limits and claustrophobia. In this review we summarized the standard procedures for imaging acquisition by TCS that are useful for diagnostic purposes in Neurology.

The exam requires specialized and well-trained professionals to obtain accurate images and relevant diagnostic information. Although ultrasound is named an "operator-dependent" technique, this can be overcome by increasing standardization of the exam, sophistication of equipment software and by expanding expertise among specialists. Perhaps this long-standing notion is now overstated.

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