ABSTRACT

In daily practice, during the performance of reports, anatomical variants, lesions and various pathologies of the central nervous system (CNS) are often encountered in which it is necessary to perform some kind of measurements in order to formulate an accurate diagnosis. These measurements allow the referring or treating physician to schedule and perform minimally invasive therapeutic procedures or those requiring major surgical intervention. We performed a description of the most frequent measurements in the CNS using computed tomography (CT) and magnetic resonance imaging (MRI).

Keywords: Central Nervous System; Computed Tomography; Magnetic Resonance Imaging

1. Introduction

The precise knowledge of the anatomy and morphology of the structures that make up the central nervous system (CNS) allows, in daily practice, the preparation of reports with a detailed description, as well as the recognition of anatomical variants and different pathologies that may occur. The measurement of these structures under normal conditions allows to categorize and recognize abnormal measures when they occur. The aim of the present work is to describe and illustrate the most frequent measurements, providing detailed information to the referring colleagues, collaborating with an accurate diagnosis and providing data that allow to choose the appropriate therapy. The most commonly used measurements in neuroimaging studies are introduced as follows.

2. Quantification of blood volume

Hemorrhagic cerebrovascular accidents (CVA) are a frequent cause of emergency department visits, accounting for 10% of total CVAs, affecting 37,000 patients per year in the United States\cite{1,2}. The main cause of hemorrhagic strokes is arterial hypertension\cite{1}. The presence of intracerebral bleeding is associated with a 40% mortality rate at one month after the event, and 60% result in disability with the need for permanent subsequent care\cite{1-3}.

Knowing the volume of bleeding is a fundamental and determining prognostic factor in its treatment and evolution. It also allows prediction...
Figure 1. Hematoma measurement; ABC/2 method; axial slices are used for this measurement; CT scan of the brain showing a voluminous right fronto-temporo-parietal hematoma, with mass effect displacing the midline and associated ventricular overturning; in (a): the maximum antero-posterior diameter (A = 9.3) and the maximum transverse diameter of the hematoma (B = 5.8) are measured; (b) shows the total number of slices in which bleeding is seen, which would correspond to C = 14 multiplied by the slice thickness 0.5 cm, which would correspond to C = 7; extrapolating the equation would be: ABC/2: 9.3 × 5.8 × 7/2 = 188.7 cm³.

of patient morbidity and mortality[1]. The greater the volume of bleeding, the worse the patient’s prognosis, especially when associated with neurological deterioration[1]. Generally, neuroradiology reports usually highlight the existence of bleeding, location and laterality, and may expand on the presence of mass effect and associated edema, but the measurements or volume of bleeding are not usually specified. The ABC/2 formula constitutes a reliable and accurate value of quantification of bleeding volume to be performed in a multiplanar computed tomography (CT) scan in an emergency[1,2].

2.1 ABC/2 method

The measurement of the volume of an intraparenchymal hematoma is performed by a method called ABC/2 which is based on the calculation of the volume of an ellipsoid or sphere[2,4–7]. It was first reported by Kwak[8]. To implement this method of measuring the volume of intraparenchymal hematomas by CT of the brain, the slice with the area of greatest bleeding is chosen and its maximum anteroposterior diameter is measured (parameter A). Parameter B corresponds to the transverse diameter of the lesion in that same slice[3,4,7]. Parameter C is the number of slices showing bleeding multiplied by the slice thickness (Figure 1)[3,4,7].

The formula is: A × B × C/2 and the final result is expressed in cubic centimeters[1]. Cohort studies recommend surgical treatment in patients with a bleeding volume greater than 25 cm³; in cases of lesions of smaller volume the indication is
variable, depending on the clinical status of the patient\[4\]. The ABC/2 method can also be used for extra or subdural hematomas\[4\]. Intraparenchymal collections greater than 25 cm\(^3\), subdural collections greater than 1 cm\(^3\), increased intracranial pressure, midline shift greater than 5 mm, dilatation of the ventricle contralateral to the hemisphere of the hemorrhagic lesion, obliteration of the medial and perimesencephalic cisterns or the III ventricle are considered signs of risk of neurological deterioration\[4\].

The ABC/2 method allows rapid quantification of the volume of a hematoma without the need for specialized software and can be performed with the patient in the emergency room. However, some authors consider the method not very specific, since it can underestimate the volume of the hematoma, especially in those bleedings with irregular borders, with polylobed contours or that do not have an elliptical shape, and other computer-assisted volumetric (planimetric) techniques that incorporate special software can be considered\[1,3–7\].

3. Midline measurement

The presence of a lesion (intra or extra-axial) with mass effect, can generate midline displacement, causing herniations, compression of basal cisterns, increased intracranial pressure and leading to death\[8,9\]. This displacement can be measured by CT or magnetic resonance imaging (MRI) in axial slices, taking as reference the position of the main medial structures such as: septum pellucidum, brain sickle, III ventricle or pineal gland\[8,9\].

To measure it, a straight line is drawn through the cerebral sickle from its rostral insertion to the dorsal insertion on the internal table\[9–11\]. In case a lesion generates mass effect and displaces the midline, the medial structures mentioned above will be displaced. To measure this displacement, a line is drawn perpendicular to the midline to where the septum pellucidum or cerebral sickle is located and the distance is measured (Figure 2)\[9–11\].

A midline shift greater than 0.5 cm is a predictor of poor prognosis for the neurological outcome of patients with head trauma admitted to intensive care\[12,13\].

4. Assessment of cerebellar tonsil herniation or descent of the cerebellar tonsils

The cerebellar tonsils are ovoid structures located on the inferior surface of the cerebellum, immediately cephalad to the occipital foramen. They owe their name to their resemblance to almonds\[14\]. The causes of tonsillar descent are various, including: increased intracranial pressure, myelomeningocele, Chiari malformation, posterior fossa hypoplasia, idiopathic scoliosis, among others\[14\]. Ectopia of the cerebellar tonsils is considered as the inferior displacement of the cerebellar tonsils when it is less than or equal to 5 mm\[14,15\].

A descent greater than 5 mm is considered a variant of Chiari malformation\[14,16\]. MRI is the modality of choice, with sagittal slices being preferred for measurement, since coronal slices make it difficult to visualize the limits of the foramen magnum\[17\]. The measurement should be taken by drawing a straight line between the basion and the opisthion of the foramen magnum. Then a line perpendicular to the first is drawn to the distal end of the herniated tonsil (Figure 3)\[18–20\].

There is disagreement among cohort studies regarding the exact value in millimeters of tonsillar
Figure 3. (a): Sagittal slices, preferably in MRI, are used to assess tonsillar descent; MRI in T1-weighted sequence of the craniocervical junction. Basion (B), Opistion (O) and the cerebellar tonsils (a) of normal location are marked; (b): MRI of the brain, T1-weighted sagittal slice in a patient with Arnold-Chiari II malformation; there is descent of the cerebellar tonsils through the foramen magnum in 16 mm; it was accompanied by syringomyelia (not shown).

descent. Table 1 summarizes the measures of tonsillar descent according to age group[20]. There is a relationship between the degree of tonsillar descent and the presence and degree of symptomatology[17] descents of less than 10 mm usually do not cause symptoms[19].

Table 1. Normal descent of the cerebellar tonsils, according to age[20]

| Decades     | Decrease in mm considered normal |
|-------------|----------------------------------|
| First       | 6                                |
| Second and third | 5                              |
| Fourth to eighth | 4                              |
| Ninth       | 3                                |

5. Assessment of encephalic atrophy

Both CT and MRI are used for the assessment of standardized measurements that allow to calculate or estimate the evolution of some diseases generally related to movement disorders or demen-
tial[21,22]. The bicaudate, Evans and bifrontal indices are obtained in axial CT and MRI slices with orbito-meatal orientation, being used to measure physiological aging and quantify the degree of brain atrophy (Tables 2–4)[22–24].

Table 2. Normal values of the indices, distributed by sex (including standard deviation)[22]

| Index     | Male     | Female    | p* value |
|-----------|----------|-----------|----------|
| Bifrontal | 0.326 +/- 0.033 | 0.319 +/- 0.031 | >0.05    |
| Bicaudate | 0.132 +/- 0.040 | 0.119 +/- 0.032 | <0.05    |
| Evans     | 0.270 +/- 0.026 | 0.263 +/- 0.026 | >0.05    |

*: The Pearson correlation coefficients obtained between the indexes and age were for the bifrontal index: r = 0.64; for the bicaudate index: r = 0.69 and for the Evans index: r = 0.60.

Table 3. Normal values of the indices distributed by sex in persons under or equal to 50 years of age (including standard deviation)[22]

| Index     | Male     | Female    | Average 50 years | p* value |
|-----------|----------|-----------|------------------|----------|
| Bifrontal | 0.308 ± 0.030 | 0.310 ± 0.033 | 0.309 ± 0.031 | >0.05    |
| Bicaudate | 0.109 ± 0.020 | 0.108 ± 0.022 | 0.108 ± 0.021 | <0.05    |
| Evans     | 0.259 ± 0.023 | 0.257 ± 0.026 | 0.258 ± 0.024 | >0.05    |

*: The Pearson correlation coefficients obtained between the indexes and age were for the bifrontal index: r = 0.64; for the bicaudate index: r = 0.69 and for the Evans index: r = 0.60.

Table 4. Normal values of the indices distributed by sex in people over 50 years of age (including standard deviation)[22]

| Index     | Male     | Female    | p* value |
|-----------|----------|-----------|----------|
| Bifrontal | 0.343 ± 0.028 | 0.327 ± 0.028 | >0.05    |
| Bicaudate | 0.153 ± 0.043 | 0.129 ± 0.036 | <0.05    |
| Evans     | 0.281 ± 0.024 | 0.269 ± 0.024 | >0.05    |

*: The Pearson correlation coefficients obtained between the indexes and age were for the bifrontal index: r = 0.64; for the bicaudate index: r = 0.69 and for the Evans index: r = 0.60.

(A) Bicaudate index: it is obtained by dividing the minimum distance of the lateral ventricles at the level of the heads of the caudate nuclei with the diameter of the skull at the same level (Figure 4).

(B) Evans index: it is calculated by dividing the maximum diameter of the frontal horns of the lateral ventricles with the maximum intracranial diameter in the same slice at the level of Monro’s foramina (Figure 5)[22–24].

A value > 0.30 indicates ventriculomegaly and can be considered pathologic, but the etiology cannot be discriminated by atrophy or other entity[22–24].

(C) Bifrontal index: calculated by dividing the
6. Cerebral peduncle angle measurement

It is a measure used to quantify the neurodegenerative disease known as Steele-Richardson-Olszewski syndrome (SROS). This pathology is characterized by selective atrophy of the brainstem, especially at the level of the cerebral peduncles, generating increased opening in the interpeduncular cistern assessed in axial CT or MRI sequences[24].

In an axial slice of a brain MRI, at the level of the mammillary tubercles, two lines are drawn parallel to the medial edges of the cerebral peduncles until they contact at their apex, measuring the angle they form (Figure 7)[2]. A cerebral peduncle angle value greater than or equal to 62° allows corroborating the diagnosis of ORS, differentiating it from other neurodegenerative pathologies with a lower degree of opening, such as Parkinson’s syndrome (53–54°) or Multiple System Atrophy (55–56°)[24].

maximum diameter of the frontal horns of the lateral ventricles and the intracranial diameter at the same level (Figure 6)[22-24].

Figure 4. Measurement of the bicaudate index should be performed with axial CT or MRI slices; CT axial brain slice; a 78-year-old male patient with cognitive impairment; a straight line is drawn measuring the distance between the medial borders of the heads of both nuclei.

Figure 5. The Evans index is obtained in axial slices in both CT and MRI. Brain MRI; axial slice in T1-weighted sequence; the distance between the frontal extensions of the lateral ventricles (A = 3.85 cm) divided by the maximum diameter of the skull in the same slice at the level of the foramen of Monro (B = 13.3 cm) should be measured; exemplifying 3.85% 13.3 = 0.28 for a 63-year-old patient with incipient intellectual developmental disorder.

Figure 6. The bifrontal index (such as that of Evans), should be obtained in axial CT or MRI images, as shown in this T1-weighted MRI, in which the distance between the frontal extensions of the lateral ventricles is measured, divided by the maximum intracranial diameter at that level; in our example it would be: 3.9% 12.6 = 0.30, indicating a normal value for a 63-year-old patient.
7. Measurement of the antero-posterior diameter of the midbrain

The reduction of the anteroposterior diameter of the midbrain at the level of the superior quadrigeminal tubercles (colliculi) is characteristic of ORS, giving rise to a typical “Mickey Mouse head” configuration (Figure 8)\(^{25,26}\). This measurement is obtained in axial T2-weighted or sagittal T1-weighted MRI slices, drawing a line from the ventral border of the midbrain, at the level of the superior colliculi, to the dorsal border\(^{25}\). The approximate anteroposterior diameter of the midbrain in patients with ORS is usually less than 14 mm; higher values allow ruling out ORS\(^{25}\).

8. Assessment of temporal horn width in Alzheimer’s disease

There are several imaging parameters to assess the degree of atrophy or involution of the encephalic parenchyma in various neurodegenerative diseases, such as Alzheimer’s disease. These measurements are indicators that show disease progression. There is involution of the encephalic parenchyma at the level of the hippocampal gyrus, amygdala and entorhinal cortex\(^{21}\). To assess it, both CT and MRI can be used to measure the width of the temporal horn of the lateral ventricles to compare the progression of the encephalic atrophy in later studies\(^{21}\).

The maximum diameter of the temporal horn is measured in an axial CT slice, then the maximum biparietal diameter is taken in the same slice to perform the quotient between both measurements (Figure 9)\(^{21}\). In normal persons, the value is 0.025. In Alzheimer’s patients it is 0.038 and 0.044 in patients with Alzheimer’s associated with extensive white matter lesions\(^{21}\).
9. Proptosis

Proptosis is the anterior displacement or protrusion of the eyeball. The term exophthalmos is used as a synonym for proptosis, although it is usually related to endocrine ophthalmopathies\cite{27}.

Proptosis can be quantified using axial CT or MRI scans showing the eyeball at its maximum diameters (even prenatally)\cite{27-30}. For this, a straight line is drawn between the two zygomatic processes (interzygomatic line). Then another line (perpendicular to the interzygomatic line) is made toward the posterior sclera: the average normal value is 9.9 ± 1.7 mm (Figure 11)\cite{27-30}.

The distance between the interzygomatic line and the anterior edge of the eyeball should be less than 21–23 mm (Figure 12)\cite{27-30}.

In MRI, a coronal slice (always at the same level) is used to measure the width of the temporal horn (Figure 10)\cite{21}. In a cohort study in patients older than 60 years they estimated temporal horn values of 6.6 mm in mild Alzheimer’s disease and 7.2 mm for advanced Alzheimer’s disease\cite{21}.

In MRI, axial CT or MRI slices can be used to measure the temporal horn; CT is performed to assess the width of the temporal horn of the lateral ventricles, which measure 7 mm; the maximum intracranial diameter is 122 mm; the ratio between both is 0.05, being compatible with the presumptive diagnosis.

Coronal MRI slices allow accurate measurement of the temporal extension of the lateral ventricle; coronal T2-weighted slice at the level of the temporal extension of the lateral ventricle; the distance of the horn width is 6.5 mm, in relation to mild Alzheimer’s disease.

Both CT and MRI in axial slices at the level of the orbits should be considered to achieve a correct measurement. MRI of orbits, T2-weighted axial view; to assess the proptosis, a line should be drawn between the zygomatic processes (red line), then a line perpendicular to the anterior line is drawn up to the posterior sclera (black line); values greater than 9.9 mm are compatible with proptosis; in our example, the distance is less, so it is considered as normal.

Another way of assessing whether there is proptosis by means of axial CT or MRI slices is shown in this T2-weighted MRI sequence, in which the interzygomatic line (red line) is drawn, then another line is drawn perpendicular to it up to the anterior border of the eyeball, being considered normal up to 21–23 mm; our example exceeds this (25 mm), so there is proptosis.
Conflict of interest

The authors declared no conflict of interest.

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