Mathematical model in post-mortem estimation of brain edema using morphometric parameters

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A B S T R A C T

Current autopsy principles for evaluating the existence of brain edema are based on a macroscopic subjective assessment performed by pathologists. The gold standard is a time-consuming histological verification of the presence of the edema. By measuring the diameters of the cranial cavity, as individually determined morphometric parameters, a mathematical model for rapid evaluation of brain edema was created, based on the brain weight measured during the autopsy. A cohort study was performed on 110 subjects, divided into two groups according to the histological presence or absence of (the — deleted from the text) brain edema. In all subjects, the following measures were determined: the volume and the diameters of the cranial cavity (longitudinal and transverse distance and height), the brain volume, and the brain weight. The complex mathematical algorithm revealed a formula for the coefficient ε, which is useful to conclude whether a brain edema is present or not. The average density of non-edematous brain is 0.967 g/ml, while the average density of edematous brain is 1.148 g/ml. The resulting formula for the coefficient ε is (5.79 x longitudinal distance x transverse distance)/brain weight. Coefficient ε can be calculated using measurements of the diameters of the cranial cavity and the brain weight, performed during the autopsy. If the resulting ε is less than 0.9484, it could be stated that there is cerebral edema with a reliability of 98.5%. The method discussed in this paper aims to eliminate the burden of relying on subjective assessments when determining the presence of a brain edema.

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1. Introduction

Brain edema is a pathological entity, which is characterized by an increased amount of fluid (water) in the brain parenchyma. Among several development mechanisms of brain edema, there are two forms that are particularly important in forensic medicine: vasogenic and cytotoxic. However, a mixed form of (the — deleted from the text) brain edema is the one that is encountered most frequently. Necrotic damage to the brain is usually followed by the interstitial and osmotic type of edema 3–5.

Current principles for evaluating brain edema during an autopsy are based on a subjective assessment of several macroscopic characteristics of the brain, such as widened and flattened waves, narrow and shallow grooves, as well as direct contact with the dura matter. Upon inspecting the brain on cross sections, narrowing of lateral ventricles, along with loose and adhesive brain tissue can be noted, depending on the phase of the brain edema. In cases of brain herniation, the presence of a brain edema is evident and its verification is straightforward. Given the fact that there is a wide range of variation of the volume of the cranial cavity, it is very difficult to diagnose a border-line case of brain edema, as well as diffuse brain edema, when the weight of the brain is within (the — deleted from the text) normal ranges. In these cases brain edema can only be diagnosed by pathohistological examination.

A more reliable method of evaluating the presence of a brain edema includes measuring the weight of the brain. The weight of a normal brain is between 1200 and 1800 g 3 or between 1100 and 1700 g according to Dawson and Neal. If the brain weighs above this range, it is considered a reliable indicator of a brain edema. However, a brain weighing over 1700 g is rarely seen in practice.
which makes weight a very unreliable parameter in verification of a brain edema. Additionally, if the brain weighs more than 1700 g, it is likely that craniomegaly is present.

The time-consuming pathohistological examination is the “gold standard” in verifying the presence of brain edema. This is due to the limits of subjective visual assessments and the wide range of baseline weight of the normal brain (particularly in cases of brain edema with previous brain atrophy as seen in the elderly). Microscopic examination shows specific halos around bodies of ganglion cells and astrocytes in the cerebral cortex, while increased looseness is seen in the white matter.

In (the – deleted from the text) search for a physical quantity or a mathematical formula that could verify the presence of a brain edema, it is necessary to review previous studies that directly measure or estimate the significance parameters. Anthropological/anthropometric research performed by a group from France aimed to determine the volume of the cranial cavity of modern Europeans. This measurement was based on Archimedes’ principles, using water and glass beads, as a criterion for normal brain weight for these subjects, anthropometric research performed by a group from France aimed to determine the volume of the cranial cavity of modern Europeans. This measurement was based on Archimedes’ principles, using water and glass beads. The obtained values were 1676.47 ± 161.26 ml for men and 1476.48 ± 102.49 ml for women.

Röthig & Schaarschmidt investigated calculating the brain weight using the body height. They determined the expected weight of the brain according to these formulas:

\[ (4) \quad M_{ERS} = 554.5 + 5.03 \text{ body height}, \]

\[ (9) \quad M_{ERS} = 464.2 + 4.95 \text{ body height} \]

where \( M_{ERS} \) represents the expected weight of the brain. However, their calculation was not based on the edematous brain and it can be used only for a normal brain that has not been affected by any pathological process.

Hausmann et al. published a morphometric research of brain edema, graded by measuring the parahypocampal gyrus, the cerebellar basal conus extension, and perivascular distension in 42 subjects with brain edema. The Röthig & Schaarschmidt method was used as a criterion for normal brain weight for these subjects, but the study failed to define these morphometric parameters as reliable for grading or even diagnosing brain edema.

Rapid and reliable assessment of the existence of a brain edema during an autopsy is an everyday challenge faced by medical examiners/forensic pathologists. The aim of this research is to reveal a mathematical relation that will determine the presence of a brain edema (especially in those cases where the edema is not evident macroscopically) using simple measurements of the diameters of the cranial cavity (as morphometric parameters that are individual, age and gender dependent) and the weight of the brain. This method, relying on a mathematical relation, would be able to determine the existence of brain edema with a certain degree of reliability in a fast and easy way without relying on subjective impressions of each examiner.

2. Methods

The study covered post mortem measurement of morphometric parameters of the skull and the brain in 200 subjects who underwent a forensic autopsy.

Measurements of morphometric parameters of the skull were related to the determination of the volume and the diameters of the cranial cavity. For the first 20 subjects, measurements were performed three times in order to increase the accuracy. The second and third measurement of the diameters of the skull was no different than the first in every case, and it was concluded that these parameters can be accurately measured by only one measurement. On the other hand, measurement of the volume of the cranial cavity and the volume and weight of the brain were performed three times for all participants and then calculated as the mean value.

2.1. Criteria for inclusion/exclusion in the study

The inclusion criteria for this study were fulfilled by considering deceased bodies of both sexes older than 18 years and younger than 80 years. We excluded people older than 80 due to the significantly higher incidence of brain atrophy in this population, which could seriously dehomogenize the sample and give false-negative results (that is, show histologically confirmed edematous brains as non-edematous).

Also, we excluded the subjects with:

- fresh skull fracture — due to the inability of accurate measurement of the diameters of the cranial cavity;
- expansive intracranial processes (tumor, epidural/subdural hematoma and subarachnoid hemorrhage) — because of the disturbed volume ratio between intracranial structures;
- hydrocephalus or enlarged brain ventricles;
- calcifications of dura matter;
- Morgagni-Stewart-Morel’s syndrome (hyperostosis frontalis interna — skull thickness greater than 12 mm in the area of frontal bone’s shell, outside the central longitudinal line of the body — common in our Mediterranean region);
- initial and advanced decay changes.

For some subjects, the measured volume of the cranial cavity differed from the actual volume by more than 1% because of deviation from the circular line that occurred during skull cutting. These subjects were also excluded from the study.

In the end, due to the rigorous criteria for inclusion in the study, measurements were made in only 200 bodies out of 1500 available autopsies. However, because of errors that occurred during the measurement (primarily due to improper cutting of the roof of the skull), final evaluation of the data was done in only 110 (respondents — deleted from the text) out of the 200 examined subjects.

2.2. Measuring the volume of the cranial cavity

After opening the skull with the electrical saw and precisely following the previously drawn circle with the center front barrel at about 2 cm above glabella and the center posterior barrel at the level of the posterior occipital protuberance, the brain and the dura mater were removed with the usual technique. Then, using the adaptive waterproof rubber, all major foramina in the base of the skull were sealed (foramen magnum, lacerum, ovale, rotundum and caroticum). The head and upper body were then placed upright so that the cross-section of the skull lies within the horizontal plane (Fig. 1).

The volume of the lower half of the cranial cavity was measured by pouring water into the lower half of the cranial cavity all the way to the edge and subsequently pouring it into a graduated cylinder. The same procedure was repeated on the upper half of the skull, and the water was poured into the same cylinder.

2.3. Measuring the diameters of the cranial cavity

The measurement of the diameters of the cranial cavity was carried out in the central sagittal plane and the widest level of the transversal plane, as well as the frontal plane for the depth. We measured the largest internal distance (the distance between opposing internal bone plates) using a caliper — slide caliper. While measuring the sagittal (longitudinal) distance, the frontal...