Experimental Analysis of Brain Surface Elastance in Cats

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Abstract

Brain surface elastance, defined as the pressure needed to compress the cortex 3 mm, was measured using the ophthalmodynamometer in six cats using three burr holes (frontal, parietal, and occipital) on each side. An intracranial mass was then used to compress the right side for 3 hours, and cardiac arrest was induced after the mass was removed. Elastance was measured four times: before insertion of the mass, 10 and 70 minutes after removal of the mass, and 60 minutes after cardiac arrest. The results showed that: brain surface elastance does not change between sides, but varies among regions with the parietal region having the highest elastance; elastance increases after compression by an intracranial mass, but not after cardiac arrest; and stiff brain tends to restore poorly. Elastance is apparently increased by the formation of edema. Measuring brain elastance may be useful in predicting brain restoration subsequent to removal of mass lesions.

Key words: brain restoration, brain surface elastance, global ischemia, intracranial mass, ophthalmodynamometer

Introduction

Poor restoration of the brain after the removal of an intracranial mass frequently causes clinical symptoms of subdural fluid collection. Factors affecting brain restoration have been investigated, especially in studies of chronic subdural hematoma. Brain restoration in elderly patients after the evacuation of chronic subdural hematoma tends to be poor, because the brain is stiff in older people. However, the relationship between brain stiffness and brain restoration has not been investigated. The elastic properties of brain tissue were previously evaluated by insertion of a pressure transducer into the brain through the intact dura, to analyze the pressure-insertion depth response using the change in cerebrospinal fluid pressure.

In this study, we employed a similar method using the ophthalmodynamometer to measure the pressure required to compress the cortex by a fixed amount (3 mm) as a measure of brain surface elastance. We then analyzed the relationship of brain surface elastance to the following: 1) defined regions of the brain, 2) pathological conditions (such as compression by an intracranial mass or global ischemia), and 3) restoration of the brain.

Materials and Methods

1. Measurement of brain elastance

The Müller ophthalmodynamometer was mounted on a stereotactic frame to exert an accurately measured pressure on the brain surface (Figs. 1 and 2). The relationship between pressure and the depth of compression was then determined. The right parietal cortex of a cat weighing 3.2 kg was compressed vertically to 5 mm depth, measuring the pressure every millimeter. The measurements were carried out three times at 60-minute intervals at the same location from the same direction. Figure 3 shows the mean values of the pressure at each compression. The coefficient of variation ranged from 0.84% to 12.2%, indicating that an interval of 60 minutes was adequate for restoration of normal brain. The pressure required to cause a depression of 3 mm was chosen as the index of brain elastance, as this depth required a pressure of about 40 mmHg, which is reported to be the safe pressure threshold for brain surface compression.
II. Animal experiments

Six adult cats weighing 2.9-3.8 kg were anesthetized using halothane inhalation at a maintenance dose of 1.0%, and immobilized with pancuronium bromide (0.5 mg/kg/hr). After tracheostomy, the left femoral artery of each cat was catheterized to monitor arterial blood pressure and collect blood samples. Another catheter was inserted into the left femoral vein for injections. Each cat’s skull was fixed in a stereotactic frame.

Three burr holes were made symmetrically on each side. All holes were 13 mm lateral from the midline. The frontal hole was 20 mm anterior, the parietal hole 5 mm anterior, and the occipital hole 10 mm posterior to the external auditory meatus. The dura was incised and the cortex was compressed vertically with the plunger of the ophthalmodynamometer through the intact arachnoid membrane. The pressure needed to depress the cortex by 3 mm was measured. Metallic cylinders 5 mm in diameter were then inserted into the three burr holes on the right side to a depth of 3 mm. These cylinders were retained in place for 3 hours. The cylinders were then removed. The pressure required to depress the cortex by 3 mm was then measured from the same direction through all six burr holes 10 and 70 minutes after removing the cylinders.

The depth of persisting brain depression 70 minutes after removal of the mass was measured. The brain elastance was compared for holes with depths of more than 1 mm (poorly restored brain group) and 0-1 mm (well restored brain group) using the ratio of brain surface elastance values measured 10 minutes after removal of the mass and before insertion. This ratio is comparable for different regions of the brain. A higher ratio indicates the brain has become stiffer (less elastic).

Cardiac arrest was then induced by rapid injection of KCl (10%, 2 ml/kg). The pressure needed to depress the cortex by 3 mm was measured 60 minutes after cardiac arrest. Finally, fractions of the cortex were dissected from all burr holes to measure the water content with linear gradient columns using a
kerosene and bromobenzene mixture. The sequential changes of the elastance in each brain region, comparisons of elastance and water content between sides and regions, and the increase in elastance ratio used analysis of variance with Scheffe's F test. All values are expressed as the mean ± SD. Results were considered statistically significant if the probability value (p) was < 0.05.

Results

Changes in the surface elastance of the brain are shown in Fig. 4. The surface elastance 10 minutes after removal of the mass on the right was significantly higher in each region compared with the elastance before insertion of the mass (frontal: F = 8.56, p < 0.01; parietal: F = 12.94, p < 0.01; occipital: F = 12.55, p < 0.01). Seventy minutes after removal of the mass, the elastance recovered to a value not significantly different from that before insertion of the mass. Before insertion, no differences were observed between sides, but elastance in the parietal region was significantly higher on both sides compared with the frontal (right: F = 14.86, p < 0.01; left: F = 12.06, p < 0.01) and occipital (right: F = 14.86, p < 0.01; left: F = 10.42, p < 0.01) regions. Sixty minutes after cardiac arrest, a significantly higher elastance was observed on the left compared with the right in the occipital region (F = 19.43, p < 0.01).

Ten regions were included in the poorly restored brain group (frontal in 3 cats, parietal in 4, and occipital in 3). Eight regions were included in the well restored brain group (frontal in 3 cats, parietal in 2, and occipital in 3). The ratio of brain surface elastance was significantly higher in the poorly restored brain group (1.77 ± 0.24) than the well restored brain group (1.51 ± 0.25) (F = 5.28, p < 0.05).

The water content on the right was significantly higher than that on the left in the frontal (F = 9.16, p < 0.01) and occipital (F = 19.41, p < 0.01) regions, but not in the parietal region. The water content in the occipital region on the right was significantly higher than that in the parietal (F = 9.56, p < 0.01) and frontal (F = 2.62, p < 0.05).

Fig. 4 Changes in brain surface elastance in each region. Values are mean ± SD. A: before insertion of the mass, B: 10 minutes after removal of the mass, C: 70 minutes after removal of the mass, D: 60 minutes after cardiac arrest. In every region on the right side, the elastance increased significantly 10 minutes after removal of the mass (*p < 0.01). The elastance in the parietal regions was significantly higher than in the frontal and occipital regions on both sides (**p < 0.01). Sixty minutes after cardiac arrest, the elastance was lower on the right compared with the left in the occipital region (**p < 0.01).
regions (Table 1).

## Discussion

Compression of the brain with an external pressure transducer for monitoring surface pressure was first reported by Schettini et al. 10) The purpose of measuring this pressure has been to investigate the relationship with intracranial pressure or cerebrospinal fluid pressure, 2,11) although the surface brain pressure should be affected by the stiffness of the brain tissue. Mchedlishvili et al. 7) compressed brain tissue with a pressure transducer and analyzed the results as mechanical properties of the brain tissue. Our method incised the dura and compressed the brain surface directly, so the pressure provides an index of only brain stiffness.

Our results show the following: 1) Brain surface elastance does not change between sides, but varies among regions, with the parietal region having the highest elastance. 2) Elastance increases after compression by an intracranial mass, but not after cardiac arrest. 3) Stiff brain tends to restore poorly.

Compression by an intracranial mass is reported to decrease cerebral blood flow, 9) which is suspected to be one of the factors increasing brain surface elastance. 12) Cardiac arrest in our experiment caused no significant increase in brain surface elastance, although the cerebral blood flow definitely decreased. Therefore, we must consider another important factor which decreases elastance: the formation of brain edema. 7) In the occipital region, where the water content was significantly higher on the right than on the left, elastance was also significantly lower. We believe this resulted from edema formation. This combination of decreased cerebral blood flow and formation of edema should be present 60 minutes after cardiac arrest.

Our results show that stiff brain tends to restore poorly. If brain with high brain surface elastance tends to restore poorly, it may be possible to predict subsequent brain restoration by measuring the elastance immediately after treatment, for example in patients with chronic subdural hematoma after hematoma evacuation. This method may be useful in predicting the persistence of a subdural space after the removal of intracranial mass such as chronic subdural hematoma, thus facilitating better treatment for patients in the postoperative period.

## References


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