MRI-based brain volumetry - dynamic measurements under various ventilation conditions

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Abstract

The aim of this work was to derive brain volumes from interventional MRI measurements and to assess slight changes under therapeutically relevant hyperventilation conditions. Image processing involved an interactive segmentation based on a watershed transformation and an automatic histogram analysis accounting for partial volume effects. Six patients undergoing brain tumor surgery in the open MR were included. For each patient, a fixed region was scanned four consecutive times immediately before skull opening. The ventilation was adjusted to reach end tidal CO2 concentrations pET(CO2) of 42, 37, 32, and 27 mmHg. Percental changes in the segmented brain volume were calculated with respect to the reference values derived at 42 mmHg (normoventilation). Control measurements were performed on four normally breathing volunteers (five acquisitions each) to estimate the level of accuracy. The method allowed a reliable brain volumetry based on the interventional MRI data despite the limited image quality of the open configuration. The intraindividual decrease of the brain volumes of the control group was found to be less than 0.05 % ($p < 0.001$). In all patients, hyperventilation lead to a relatively small but significant ($p < 0.05$) reduction in the mean brain volume. The relative differences at pET(CO2) = 37, 32, and 27 mmHg were calculated as 0.41 % mean, 0.66 %, and 0.68 %, respectively. To our knowledge, this work is the first report on reliable dynamic measurements of human brain volume changes derived from interventional MR data under various ventilation conditions. Up to pET(CO2) = 32 mmHg, the brain volume seems to decrease with the degree of hyperventilation. A further reduction in pET(CO2) did not lead to a significant further decrease.

Introduction

Ventilation-induced changes in the intracranial compliance are typically measured with invasive brain pressure sensors. This, however, is a rather indirect way to monitor the real changes in brain volume occuring under different ventilation conditions. The aim of this work was to acquire brain volume data from interventional MRI measurements and to assess slight changes under therapeutically relevant hyperventilation.

Materials and Methods

Brain volume data were acquired in an open 0.5 T MR scanner (Signa SP/i, GE) using a 3D SPGR sequence (TE 2.7, TR 13.3, coil FLEX3, matrix 256x192, 60 slices, slice thickness 2.0mm, no gap, TA 5:20 min. Image processing involved an interactive watershed segmentation and an unbiased model-based histogram analysis on the masked brain data. Six patients undergoing brain tumor surgery in the open MR were included in this study. Immediately before skull opening, a fixed region was scanned four consecutive times. The ventilation was controlled by volume and adjusted to reach end tidal CO2 concentrations pET(CO2) of 42, 37, 32, and 27 mm Hg. Cardiovascular and arterial blood gas parameters were recorded along with the ventilation values. Percental changes in the segmented brain volume were calculated with respect to the normoventilation values at 42 mm Hg. Control measurements were performed on four normally breathing volunteers (five acquisitions each).

Results

Brain volumetry based on interventional MRI measurements was possible despite the limited image quality of the open configuration. For the non-ventilated group, the intraindividual relative brain volume decrease was limited to 0.05 % ($p < 0.001$). For all patients, however, hyperventilation lead to a significant ($p < 0.05$) reduction in the mean brain volume. The mean relative differences at pET(CO2) = 37, 32, and 27 mm Hg were calculated as 0.42 %, 0.66 %, and 0.68 %, respectively. This corresponds to a volume reduction of about 5.2 and 8.3 cm^3, respectively. For moderate reductions in pET(CO2), the brain volume changes correlated with the degree of hyperventilation. A further reduction down to 27 mm Hg did not yield any significant further reduction.

Fig. 1 Positioning of neurosurgical patients in the interventional 0.5 T MRI scanner (GE Signa SP/i).
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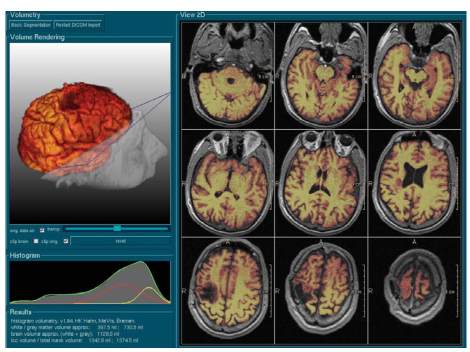

Fig. 2 Screenshot of research platform ILAB4 (MeVis, Bremen) during segmentation of supratentorial brain structures, volume rendering and histogram analysis based on three tissue types (cerebrospinal fluid, white and gray matter).

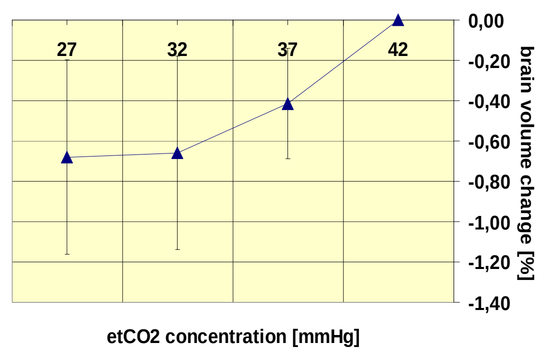

Fig. 3 Relative brain volume changes in six patients undergoing brain tumor surgery in the open MRI. Mean (%)± standard deviation as a function of controlled hyperventilation.

Discussion

This work represents a first reliable dynamic measurement of human brain volume changes of less than one percent derived from interventional MR data under various ventilation conditions. Most surprisingly, a reduction of the end tidal CO2 partial pressure pET(CO2) below 32 mmHg did not result in a further decrease in the supratentorial brain volume. This is in contrast to the general belief that a hyperventilation induces reduced intracranial blood volumes for arterial blood pressures paCO2 down to 20 mm Hg. So far, this effect has only been demonstrated for a rather limited number of patients undergoing brain tumor surgery and the corresponding error bars are quite large. More therapeutically relevant information is expected from future studies on larger and more specific patient collectives.

References

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