Electrical Conductivity Characteristics of Meningiomas: Noninvasive Assessment using Electric Properties Tomography

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Target audience: Radiologists, scientists and clinicians engaged in brain tumor imaging and noninvasive measurement of electrical conductivity by MRI

Background and Purpose: Tumor impedance measurement used to locate brain tumor during surgery has reported that meningiomas have high electrical impedance, i.e., low electrical conductance[1]. Nevertheless, only five cases have been evaluated, and it is not known whether electrical conductance can be used to distinguish meningiomas from other tumors especially those which share similar MRI features (e.g., lymphomas). It is also not known if electrical conductance of meningioma varies with tumor grade or histological subtype. Recent development of Electric Properties Tomography (EPT) has allowed measurement of electrical conductance of brain tumors noninvasively and in vivo[2]. This study aimed to characterize the electrical conductivity characteristics of meningioma by using EPT.

Methods: MRI consisted of EPT, pre- and post-contrast-enhanced T1-weighted imaging, T2-weighted imaging, FLAIR imaging, and diffusion imaging, was conducted in 11 patients with meningioma (incl. 5 meningothelial meningiomas, 2 atypical meningiomas, and 1 microcystic meningioma). For comparison of conductivity characteristics, MRI was also performed in 5 patients with lymphoma and 8 patients with low grade glioma. The choice of these tumors was based on the fact that lymphomas often share similar MRI features to meningiomas and the electrical conductivity characteristics of glioma have been documented[3]. The conductivity maps were calculated from the phase images of EPT, using the formula $\sigma(r) = (2\mu_0\omega)^{-1}\,\Delta\varphi(r)$, where $\sigma(r)$ = conductivity, μ_0 = mean magnetic permeability of the body, ω = Larmor frequency, Δ = Laplacian operator, and $\varphi(r)$ = transceive phase. In each patient, the tumor was semiautomatically segmented using the pre- and post-contrast-enhanced T1-weighted imaging, T2-weighted imaging, and FLAIR imaging. In patients with meningioma, gray matter was also segmented to evaluate conductivity difference between the tumor and adjacent brain parenchyma. The segmented areas were then superimposed onto the co-registered conductivity maps; and conductivity histograms were extracted. The major histogram metrics (normalized peak height, peak position, maximum, minimum, width, median, and mean) of meningiomas were then compared with those of normal gray matter, lymphomas and low grade gliomas, and among meningioma grades and histological subtypes. Correlation with mean diffusivity (MD) values derived from diffusion imaging and proliferation index (Ki67) was also tested. Paired t-tests, one way analysis of variance (ANOVA), and Pearson's product-moment correlation analysis were used to determine statistical significance at $P<0.05$. Validity of noninvasive electrical conductivity measurements by EPT was checked by comparing the conductivity value of chicken breast phantom measurable by EPT and that by direct measurement using a Dielectric Probe and an Analyzer.

Results and Discussion: The normalized peak height, peak position, maximum, median and width of conductivity histograms of meningioma varied significantly from those of gray matter (Fig 1; paired t-tests, $P<0.01$), which suggests that meningiomas can be distinguished from adjacent brain parenchyma by their conductivity characteristics. Meningiomas had significantly lower minimum and broader width of conductivity histograms than lymphomas (Fig 2; one way ANOVA and posthoc Tukey tests, $P\leq0.02$). The conductivity histograms did not vary significantly between meningiomas and low grade gliomas. These observations reflect a higher degree of tumor heterogeneity in meningiomas compared to lymphomas, and that meningiomas share similar electrical conductivity characteristics to low grade gliomas. The conductivity histogram metrics did not vary significantly with meningioma grades and histological subtypes; but limited sample size for each grade or subtype may be responsible. Tests of correlation revealed an inverse correlation between the maximum conductivity and minimum MD values of meningiomas (Pearson's product-moment correlation analysis, $r=-0.68$, $P=0.02$). This may imply that ion mobility is not the sole contributing factor for tumor conductivity values in meningiomas. No significant correlation was observed between the conductivity histogram metrics and Ki67. The conductivity value of chicken breast phantom measurable by EPT approached that of direct measurement (973 mS m^{-1} vs 853 mS m^{-1}), suggesting that EPT can be used to noninvasively assess the conductivity characteristics of tissues.

Conclusions: The conductivity characteristics of meningiomas were evaluated noninvasively. EPT allows characterization of tumor conductivity, which may aid in diagnosis, monitoring, and management of these tumors.

References: (1) Organ L, Tasker RR, Moody NF, et al. Brain tumor localization using an electrical impedance technique. J Neurosurg 1968; 28(1): 35-44. (2) Katscher U, Kim DH, Seo JK. Recent progress and future challenges in MR electric properties tomography. Comput Math Methods Med. 2013; 2013: 546562. (3) Tha KK, Stehning C, Suzuki Y, et al. Noninvasive evaluation of electrical conductivity of the normal brain and brain tumors. Proc. Intl. Soc. Mag. Reson. Med. 2014; 22: 1885.

Figure legends: Fig 1 (below, left). The average histograms of meningiomas (blue) and normal gray matter (red). The major histogram metrics varied significantly between these two tissue types (paired t-tests, $P<0.05$). Fig 2 (below, middle and right). The representative conductivity maps and the corresponding morphological images (contrast-enhanced T1-weighted image or FLAIR image) of meningothelial meningioma (a), low grade glioma (b), and lymphoma (c), and the plots of the minimum and width of conductivity histograms of these tumors (one way ANOVA and posthoc Tukey tests)(d).