Finite Element Analysis of TTFields In Brain Metastasis According To The Types of Cerebral Edema

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Introduction

TTFields are being investigated for treatment of brain metastasis. Although vasogenic edema is the most common type of associated cerebral edema, other forms of edema might arise within the brain due to prior treatment or other confounding effects. Therefore, we seek to determine differences in TTFields intensity for vasogenic, interstitial and cytotoxic edemas. Finite element analysis was performed using semi-autosegmentation techniques in SPM8 and ScanIP of a MRI dataset from a 58 year old male with significant cerebral edema surrounding a solitary left frontal brain metastasis from squamous cell carcinoma of t he left lower lung, and COMSOL Multiphysics, followed by analysis using (Electric Volume Histogram) EVH, (Specific Absorption Rate Volume Histogram) SARVH, (Current Density Volume Histogram) CDVH, and (Plan Quality Metrics) PQM.

Patients and Computational Methods

1. A three-dimensional finite element mesh was generated from the semi-automatically segmented MRI dataset and then imported to COMSOL Multiphysics (Burlington, MA) for FEA using the AC/DC module.
   - The edema was assigned different electrical conductivity values equivalent to plasma (0.71 [S/m]), cerebrospinal fluid (2.0 [S/m]), and gray matter (0.14 [S/m]) to model as vasogenic, interstitial and cytotoxic edema, respectively.
2. Plan Quality Metrics (PQM) derived from EVH, SARVH and CDVH were used to quantitatively compare TTFields coverage.
3. Total coverage of the GTV under 3 types of edema was compared and denoted as area under the curve for EVH (E_{AUC}), SARVH (SAR_{AUC}) and CDVH (CD_{AUC}).

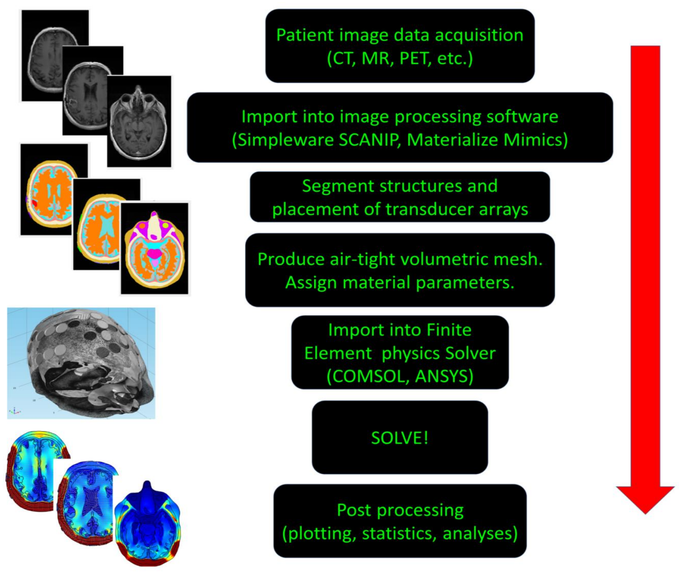

Figure 1. Finite element analysis workflow.

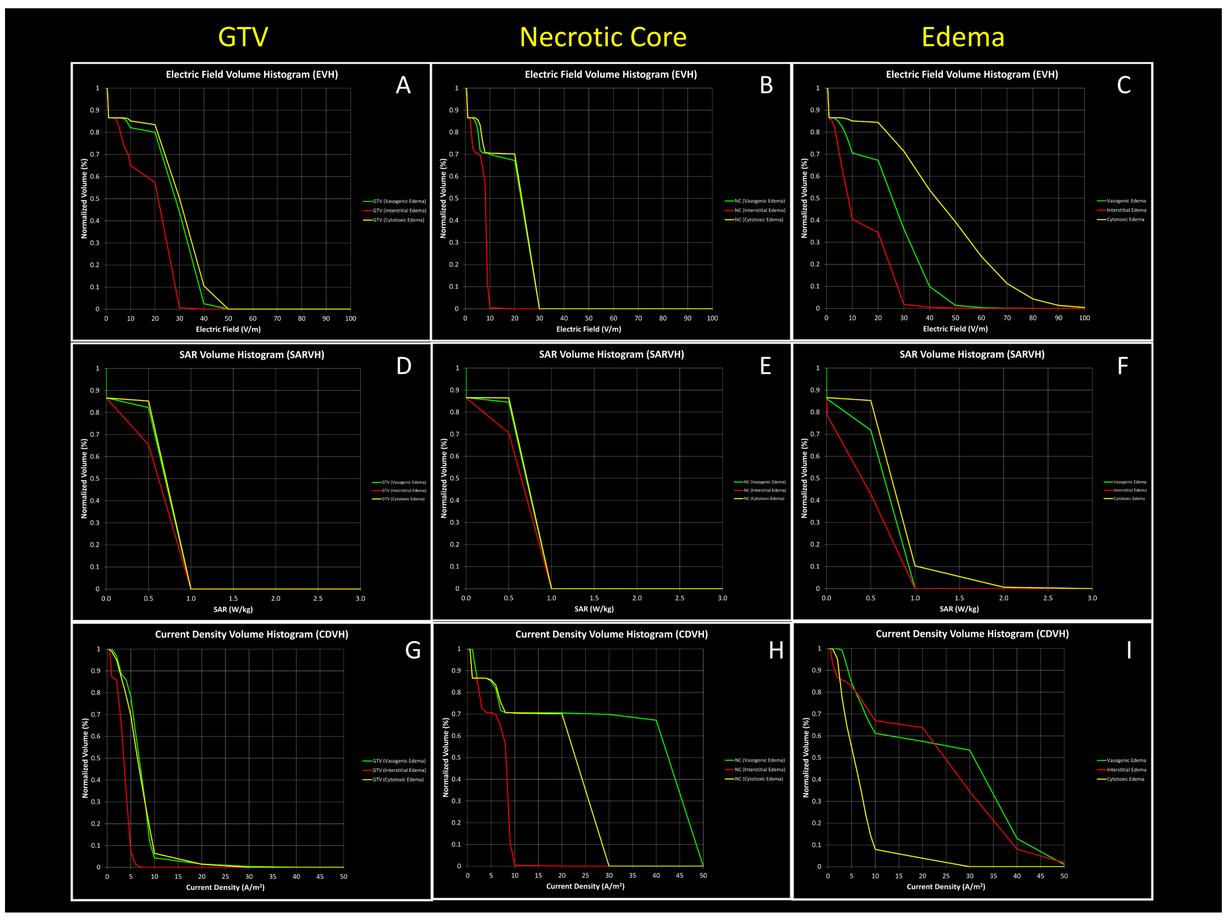

Figure 2. **(A-C)** EVH (Electric Volume Histogram), **(D-F)** SARVH (Specific Absorption Rate Volume Histogram), **(G-I)** CDVH (Current Density Volume Histogram) of the GTV (gross tumor volume), necrotic core, and edema site for various types of edema.

Varying cerebral edema alters TTFields distribution

1. Differences in TTFields distribution was quantified using the E_{AUC}, SAR_{AUC}, CD_{AUC}, $E_{75\%}$, $SAR_{75\%}$, and $CD_{75\%}$.
2. Different types of cerebral edema was shown to have influenced the distribution of TTFields on the coverage of the GTV:
   - The $E_{50\%}$ and E_{AUC} was greatest when the edema was modeled as cytotoxic edema
   - The $E_{50\%}$ and E_{AUC} was least when the edema was modeled as interstitial edema.
   - The variance of E75% is more than a 3-fold between interstitial and cytotoxic edemas, or 7.1 and 23.9 V/m, respectively.
3. Power deposition does not differ significantly between the 3 types of edema.
4. Current density is lowest in GTV and necrotic core when associated with interstitial edema.
5. Current density is lowest in edematous brain when associated with cytotoxic edema.

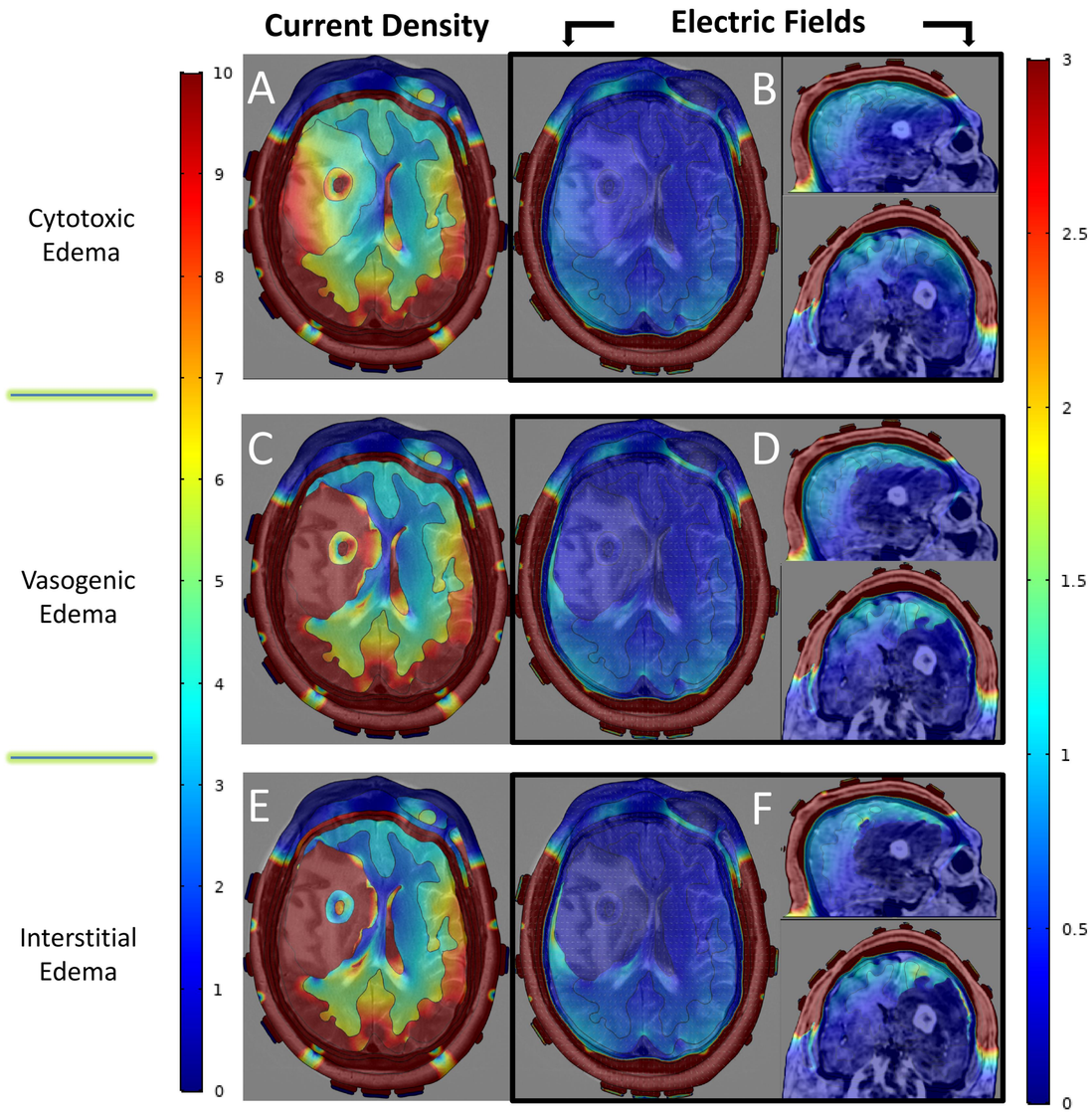

Figure 3. (A) 2-D axial view of current density distribution along with **(B)** the axial, sagittal and coronal view of electric fields distribution for the cytotoxic edema model. **(C)** 2-D axial view of current density distribution along with **(D)** the axial, sagittal and coronal view of electric fields distribution for the vasogenic edema model. **(E)** 2-D axial view of current density distribution along with **(F)** the axial, sagittal and coronal view of electric fields distribution for the interstitial edema model.

Conclusions

1. Finite element modeling of cerebral edemas provided an important insight on how various types of edema altered TTFields distribution within the brain.
2. Various types of cerebral edema exhibits differences in TTFields distribution
3. The analysis of current density distribution revealed significant differences between these three types of edema due to variations in water content and the corresponding electrical conductivity values.

References

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