MR based reconstruction of the local SAR deposition using CSI-EPT

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INTRODUCTION

SAR assessment is of major interest in applications such as Hyperthermia and MRI. To determine the SAR deposition, knowledge of the tissue electric properties (conductivity σ and permittivity ε_r) and the amplitude of the electric field are required. Various methods, such as Electric Properties Tomography (EPT) [1] and Local Maxwell Tomography [2], have been introduced to reconstruct the electric properties based on B1+ fields. More recently an iterative method based on contrast source inversion (CSI-EPT) [3,4] has been introduced that reconstructs the electric tissue properties as well as the electric field. CSI-EPT does not assume piecewise constant media and works with global integral representations for the fields. Simulation studies have demonstrated its ability to accurately reconstruct the electric properties [4] and since CSI-EPT reconstructs the electric field as well, it is a promising method to perform local SAR assessment. In [3] the potential of CSI-EPT to reconstruct electric properties and the amplitude of electric field was demonstrated in pelvic-sized phantom experiments. In this study, we investigate the applicability of 2D CSI-EPT for in vivo SAR assessment. Such a two-dimensional approach provides a good approximation of the fully vectorial three-dimensional electric field in the mid-plane slice of a 3T body coil [5]. In this abstract, we demonstrate the effectiveness of 2D CSI-EPT to reconstruct the SAR within this mid-plane and provide a validation of our approach.

MATERIALS AND METHODS

The CSI-EPT method is based on two domain integral representations for the electromagnetic field. The first representation is known as the data equation and relates the measured B1+ field to the so-called contrast source $\mathbf{w}(\boldsymbol{x})=\chi(\boldsymbol{x})\mathbf{E}(\boldsymbol{x})$, which consists of the product of the unknown profile function $\chi(\boldsymbol{x})= \varepsilon_r(\boldsymbol{x})-1-j\ \sigma(\boldsymbol{x})/(\omega\varepsilon_0)$ and the unknown total electric field E. Although we do not know this field, we do know that it must satisfy Maxwell's equations. In integral form, this amounts to requiring that the electric field satisfies a so-called object equation. This equation acts as a constraint for the data equation. In CSI-EPT [3,4], we now iteratively update the contrast source and contrast function by minimizing the objective function $F(\mathbf{w}, \chi)=[F_{\text{data}}(\mathbf{w})+F_{\text{object}}(\mathbf{w}, \chi)]F_{\text{TV}}(\chi)$ at every step, where $F_{\text{data}}(\mathbf{w})$ and $F_{\text{object}}(\mathbf{w}, \chi)$ measure the discrepancy in satisfying the data and object equation, respectively, and $F_{\text{TV}}(\chi)$ is a multiplicative regularization term, which ensures that rapid variations due to noisy data are suppressed during the minimization procedure. In addition, data obtained for n different phase settings of the transmit coil can be handled simultaneously by minimizing the total objective function $F^{\text{tot}}(\mathbf{w}, \chi)=\Sigma_n[F_{\text{data}}(\mathbf{w})+F_{\text{object}}(\mathbf{w}, \chi)]F_{\text{TV}}(\chi)$, which consists of a summation of regularized objective functions for each phase setting separately. Upon completion, the algorithm produces a reconstructed contrast function χ and contrast source **w** and since $\mathbf{w}(\boldsymbol{x})=\chi(\boldsymbol{x})\mathbf{E}(\boldsymbol{x})$, we have essentially reconstructed the electric field as well. Mathematical details about updating with and without TV regularization can be found in [6], among others.

RESULTS

In Figs. 1(a,b) the actual σ and ε_r profiles of a female pelvis model (Ella, IT'IS) in the mid-plane of the RF coil are shown. The electric properties are based on [7] at 128MHz. The RF field is excited by 16 line sources (driven in quadrature at 128MHz) symmetrically located around the object. We assume that the B1+ transmit phase is available without receive phase contamination. We subsequently apply 2D CSI-EPT to the B1+ field as generated by 16 line sources. The reconstructed electric properties produced by 2D CSI-EPT are shown in Figs. 1 (d,e). Furthermore, the true 2D |E|-field (Fig. 1c) is well approximated by the reconstructed |E|-field (Fig. 1f). The SAR_{10g} computed with the 2D model (Figs. 1a-c) (shown in Fig. 1h) is also well approximated by the reconstructed SAR_{10g} based on CSI-EPT reconstructions of the electric properties and the electric field (Figs. 1d-f) (shown in Fig. 1i).

To further validate our 2D approach, the fully vectorial 3D electromagnetic field in a realistic 3T body coil [8] is determined using FDTD. The resulting SAR distribution in the mid-plane of the coil is shown in Fig. 1g. We observe that the reconstructed SAR_{10g} based on 2D CSI-EPT (Fig. 1i) is in good overall agreement with the SAR distribution based on full 3D FDTD simulations even though 2D CSI-EPT is fully two-dimensional. This example illustrates the ability of CSI-EPT to reconstruct the local SAR_{10g} deposition. Further improvements can be realized by extending CSI-EPT to three dimensions and by incorporating the MRI shield into the CSI formalism. 2D CSI-EPT already produces fairly accurate SAR reconstructions, however, as long as the electromagnetic field has an approximately two-dimensional (E-polarized) structure.

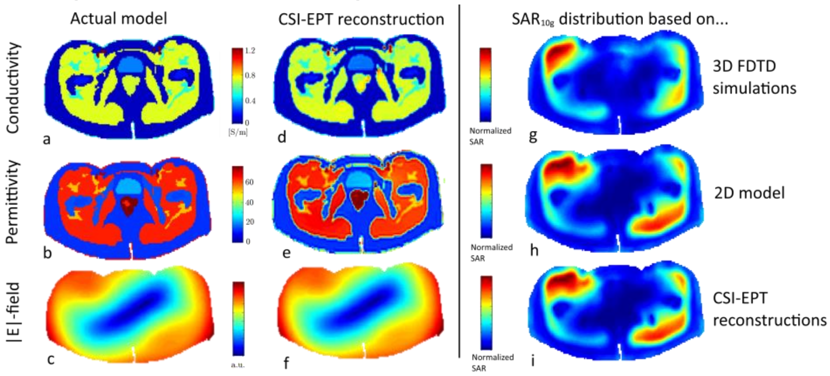

Fig 1. Original σ and εr profiles (a,b) and the |Ez|-field (c). The reconstructed profiles (d,e) and |Ez|-field (f) obtained with CSI-EPT after 1000 iterations. (g) The SAR_{10g} distribution based on full 3D FDTD simulations, (h) the SAR_{10g} distribution based on (a-c) and (i) the SAR_{10g} distribution based (d-f).

CONCLUSIONS

This study demonstrates the ability of 2D CSI-EPT to reconstruct the SAR distribution based on B1+ fields within the mid-plane of the RF coil. Good agreement with fully three-dimensional FDTD simulations was observed and 2D CSI-EPT therefore seems to be a potential tool to improve current SAR assessment. Future work will focus on the effects of the transceive phase approximation on SAR reconstruction and on developing a 3D CSI-EPT method that allows for complete local SAR assessment inside and outside the mid-plane of the RF transmit coil.

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