Electric Properties Tomography: Calculation of the in-vivo electric field within realistic computation times using quasi-stationary zooming

C. A. Van den Berg[1], M. Boute[1], B. Van den Bergen[1], J. J. Lagendijk[1], and U. Katscher[2]

[1]Dept. of Radiotherapy, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands, [2]Philips Research Europe-Hamburg, Hamburg, Germany

Introduction

Measuring dielectric properties of the human body has the potential to serve as an additional functional diagnostic parameter or for more precise determination of local SAR values during an MRI exam. Recently, a method called Electric Properties Tomography (EPT) has been introduced, and its feasibility to determine in vivo dielectric properties has been demonstrated [1]. Using an iterative computation scheme the dielectric properties can be mapped from the curl of the measured transverse magnetic field. See equation 1. In each iteration the axial electric field Ez has to be re-calculated based on the newly computed dielectric anatomy. To perform this in a feasible time and resolution, conventional computation schemes such as the Finite Difference Time Domain (FDTD) technique are too slow. In this study we propose to use a technique called quasi-stationary zooming for this purpose. The aim of this study was to evaluate the impact of the approximations of this computational scheme on the EPT results.

$$\frac{\delta_x H_y(\vec{r}) - \delta_y H_x(\vec{r})}{E_z(\vec{r},\kappa_i)} = \kappa(\vec{r})_{i+1} = \sigma(\vec{r})_{i+1} + i\omega\varepsilon_0\varepsilon_r(\vec{r})_{i+1} \qquad (1)$$

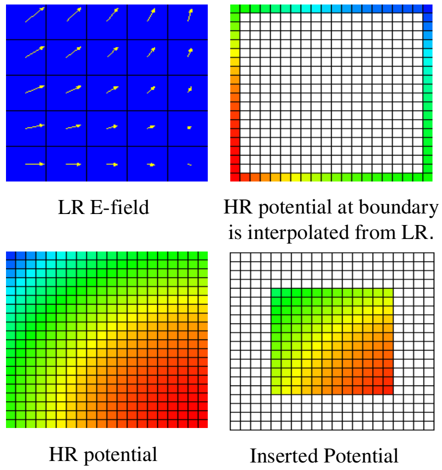


Fig. 1. The HR potential at boundary is determined by interpolation of LR potential. To correct for the influence of this incorrect boundary condition a corresponding mask is applied.

Theory of quasi-stationary zooming

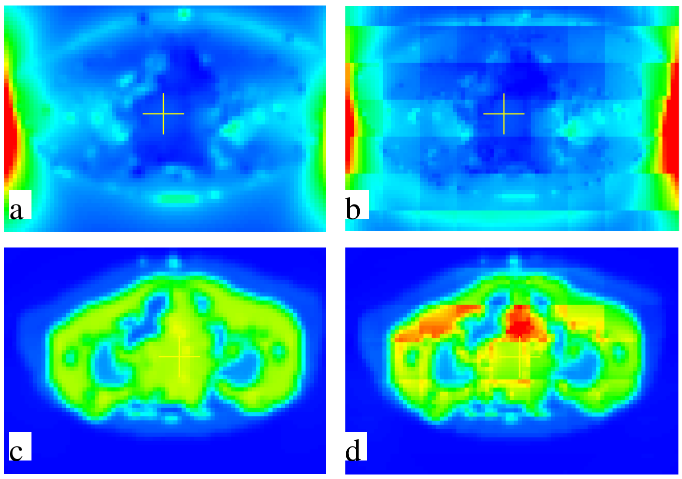
The quasi-stationary zooming technique calculates for a sub-volume (zoom volume) in the patient a high resolution scalar electric potential. This procedure is illustrated in Figure 1. First an electric potential on the zoom volume's surface is computed based on a low-resolution (LR) electric field from a separate FDTD simulation run. With this potential distribution as a boundary condition and the high resolution (HR) dielectric anatomy of the zoom volume, the high-resolution potential distribution can be computed by solving the quasi-stationary approximation of the Maxwell equations [2]. This electric field is calculated by taking the gradient of the potential. The procedure is repeated for several just-touching zoom volumes to obtain the high-resolution scalar potential for an arbitrary large volume of interest. This quasi-stationary model is valid as long as the size of the zoom volume is small compared to the wavelength. Furthermore, the size of the zoom volume should be smaller than the field penetration depth.

Materials and Methods

To test the validity of quasi-stationary zooming for EPT, we modelled a simple test MR transmit coil consisting of only two antennas placed on the negative and positive x-axis. The size of the computational domain was 95x95x125 cm^3. We inserted a dielectric model of the female pelvis in the coil. Two FDTD simulations were performed for this geometry, a high (5x5x5 mm^3) and a low (15x15x15 mm^3) resolution simulation. The high resolution simulation serves two purposes: (1) to obtain the curl of the transverse magnetic field to mimic measured data and (2) to provide the golden standard Ez field from which the golden standard EPT distribution is calculated. This optimum distribution corresponds to an ideally converged iteration of the EPT algorithm [1]. The low resolution FDTD simulation was used to compute a low resolution potential at the boundaries of the zoom volumes. The quasi-stationary zooming technique was applied to calculate an Ez field distribution with a 5x5x5 mm^3 resolution for a volume of 40x32x13 cm^3. In this study a zoom volume of 7.5x7.5x7.5 cm^3 was used. Finally, the dielectric properties were computed using only one EPT iteration for the high resolution FDTD as well as the zoomed Ez field. All computations were performed on a standard PC with a 2.6 GHz CPU and using Linux as an operating system.

Results

In Figure 2 the Ez fields are compared for the high resolution FDTD and the zooming technique. The LR and HR FDTD simulation required 10 and 420 min. computation time respectively. The zooming required another 10 minutes. As can be observed, the zoomed Ez field shows a reasonable correlation with the FDTD results. Similar behaviour can be seen in the EPT results. Although the global correspondence to the golden standard FDTD is good, there are regions in the zoomed EPT results which show higher values than the FDTD result. For these regions the zooming technique under-estimates the Ez values. Since the EPT algorithm requires a division of the curl of the magnetic fields by Ez, these errors become very visible in the EPT result. Maximum overestimation in κ was 20%. Future investigations will be aimed at minimizing this error.



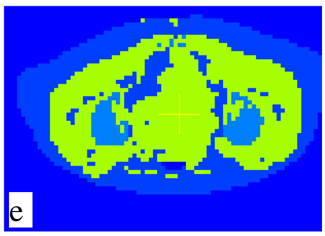


Fig. 2. The HR Ez field distribution calculated with FDTD (a) and QS-zooming (b). The resulting EPT κ-distribution in the female pelvis using golden standard HR FDTD (c) and QS-zooming (d). The actual input κ-distribution is shown in e. κ-colorbar scales from 0 to 1.3 S/m

Conclusions

The quasi-stationary zooming technique enables to perform EPT in vivo within practical calculation times. Quantitative EPT requires a high level of accuracy in electric field computation. Although quasi-stationary zooming technique introduces some errors in the EPT results, it is believed that this computation scheme can provide quantitative information about dielectric properties.

1. Katscher et al. P In vivo determination of electric conductivity and permittivity using "Electric Properties Tomography". , ISMRM 15 (2007) 1774

2. Van de Kamer et al , Quasistatic zooming of FDTD E-field computations: the impact of down-scaling techniques, Phys Med Biol. 46 (2001) 1539-51