MIDA: a virtual model of the human head and neck

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Virtual anatomical models together with simulations are valuable tools that complement experimental testing for analysis of safety and efficacy of medical devices. They have been embraced particularly for exposure assessment and dosimetric applications. Multiple voxel- and surface-based whole- and partial-body models – typically segmented from either magnetic resonance imaging (MRI) or computed tomography (CT) data, or photographs of cryosections – have been proposed in the literature, typically with spatial resolution in the range of 1–2 mm and with 10–50 different tissue types resolved. We have developed a multimodal imaging-based detailed anatomical model of the human head and neck, named "MIDA", to be used primarily in applications related to interactions of tissues with electromagnetic (EM) fields, e.g., low frequency exposure safety, deep brain stimulation, and other electrical or magnetic stimulation based treatment. The model was obtained by integrating three different MRI modalities, the parameters of which were tailored to enhance the signals of specific tissues: i) structural T1- and T2-weighted MRIs; a specific heavily T2-weighted MRI slab with high nerve contrast optimized to enhance the structures of the ear and eye; ii) magnetic resonance angiography (MRA) data to image the vasculature, and iii) diffusion tensor imaging (DTI) to obtain information on anisotropy and fiber orientation. First, a combination of affine and non-rigid registration algorithms was used to co-register the images. Registration allowed the multi-modality head MRI scan types acquired to be integrated into a single representation with one coordinate system, while taking advantage of the complementary information provided by the different image sources for improvement of the segmentation. Semi-automatic segmentation was performed using the iSeg software (Zurich MedTech, Zurich Switzerland), switching among the available datasets depending on which showed the best contrast for the specific structure to be outlined. Segmentation was followed by surface extraction, simplification, and smoothing. Special techniques were developed to prevent the introduction of self-intersections, gaps, and overlaps.

The unique multimodal high-resolution approach enabled the resolution and segmentation of 142 structures (Figure), including several distinct muscles, bones and skull layers, arteries and veins, as well as salivary glands. The model offers also a detailed characterization of eyes, ears, and deep brain structures. A special automatic atlas-based segmentation procedure was adopted to include a detailed map of 38 nuclei of the thalamus and midbrain into the head model. The integrated DTI tensor information permits the assignment of location-specific anisotropic brain tissue parameters. The suitability of the model to electromagnetic simulations involving different numerical discretization approaches, as well as DTI-based tensorial electrical conductivity, has been examined in several case studies, such as transcranial alternating current stimulation and deep brain stimulation.