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# A boundary element approach to relate surface fields with the specific absorption rate (SAR) induced in 3-D human phantoms

Oriano Bottauscio [a,*], Mario Chiampi [b], Luca Zilberti [a]

[a] Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce, 91, I-10135 Torino, Italy
[b] Dipartimento Ingegneria Elettrica, Politecnico di Torino, Italy

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ABSTRACT

This paper proposes a numerical technique, based on the boundary element method, for the reconstruction of the specific absorption rate in 3-D human phantoms. The method intends to relate electric and magnetic field measurements on the surfaces of a virtual box surrounding the considered phantom with the SAR values within the body. After a description of the adopted boundary element approach, an analysis of the influence on the SAR reconstruction accuracy of several parameters, such as size and shape of the virtual box, or position and number of the measurement points, is presented. The effect of the field source and supply frequency is also investigated. Finally, an extension of the approach to non-homogeneous phantoms is discussed.



## 1. Introduction

Specific absorption rate (SAR) caused by the human exposure to radiofrequency electromagnetic fields is the basic restriction established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in the frequency range 100 kHz–10 GHz [1]. In order to verify the compliance with the ICNIRP limits, the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) established experimental and/or computational procedures to determine SAR levels for various exposure conditions.

In particular, the SAR calculation within a human body exposed to radio-frequency (RF) fields has been largely considered in the literature in the last two decades and references to computational approaches have been explicitly included in many technical standards. Starting from the first numerical estimations based on very simple models of the human body (e.g. homogeneous spheres or head shaped volumes [2,3]), more complex approaches, involving anatomical human models obtained by the magnetic resonance imaging (MRI), have been developed [4]. As a consequence of the use of voxel body models during the '90s, finite-difference-time-domain (FDTD) technique rapidly developed for dosimetric studies of human exposure to a variety of RF electromagnetic sources (see for example [5,6]), under both far-field [7] and near-field (e.g. mobile phones) [6,8–10] exposure conditions. FDTD technique is also explicitly cited in several standards related to human exposure to the RF electromagnetic fields [11–13].

Under near-field conditions, but with the source not located in close proximity to the human body, the use of FDTD becomes critical, as a consequence of the need of enlarging the domain under study to include both the human body and the source. The problem has been partially faced through the finite integration technique (FIT), originally developed by Weiland [14] and made available for instance in the commercial software [15], which is largely adopted for dosimetric studies (see, for example, [16,17]). Other interesting approaches adopt hybrid techniques, coupling finite element (FEM) and method of moment (MoM), suitable to face the complexity of heterogeneous human models and the presence of far RF sources [18]. Although the boundary element method is well appropriate for handling complex 3-D geometries (e.g. the human body), without requiring the meshing of the region between the phantom and the sources, it has not been frequently applied to the evaluation of human exposure to electromagnetic fields, because it is not suited to handle the strong heterogeneous properties of tissues in anatomical phantoms. Nevertheless, some successful applications of boundary element technique to dosimetric studies in the presence of homogenous or weakly heterogeneous phantoms can be found in [19–24].

Despite the large use of numerical computational tools for dosimetric studies, little information is available in the literature on the accuracy of these numerical solutions for heterogeneous complex bodies. Some works have faced this problem, by specifically analyzing the factors that influence the accuracy in numerical reconstruction of SAR [25] or by comparing the computational results with experiments developed on simplified phantoms of human bodies [26,27]. A reasonable amount of correlation generally exists between computed and measured SAR distributions, even if some discrepancies are usually found on the absolute

* Corresponding author. Tel.: +39 011 3919828; fax: +39 011 3919849.
*E-mail address:* o.bottauscio@inrim.it (O. Bottauscio).

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