Next Generation Anatomical Human Models and Thermal Application of Their Detailed Vasculature

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Introduction: The latest generation of the Virtual Population (ViP) [1] includes YOONSUN V3.1 [2], a female model with unprecedented detail in nerve and vasculature anatomy, illustrated in Fig. 1. The newly segmented fine vessels (<2 mm) allow us to study the impact of the vasculature on in silico temperature increase estimations. While the impact of microvasculature is typically handled through a homogeneous and distributed heat-sink term, the thermal impact of large vessels is typically simulated by imposing a Dirichlet boundary condition [3] (37°C). An intermediate approach assigns the small vessels with a high perfusion of 250 times the normal perfusion of muscle. We compared these three different simulation approaches for the detailed vasculature in the YOONSUN model. This provides insight into the influence of the vessel tree detail on thermal modelling and provides an estimation of an upper bound on the impact.

Methods: ViP model YOONSUN was investigated in the abdominal MRI imaging position at 3T, which constitutes a high exposure scenario [3] with a thermal hotspot in the right forearm. The Pennes bioheat equation [4] has been applied with thermo-physical and -physiological parameters from the literature [5]. The exposure level was normalized to the first level controlled operating mode [6]. Thermoregulated perfusion values were not considered for this study.

Results & Conclusions: Results are summarized in Fig. 2. Two veins and one artery can be seen in the voxel slice (Fig. 2a), as well as eight newly segmented small vessels. The Dirichlet boundary is assigned to all large vessels. The small vessels are assigned as Dirichlet (Fig. 2b), as highly perfused (Fig. 2c), and as fat tissue (Fig. 2d). While the simulated small/medium-sized vessels considerably alter the temperature distribution around their location, the actual peak temperature increase in the thermal hotspot is affected less – a reduction from 47.4°C to 45.4°C, 20% of the temperature increase. The hotspot remains at the same location. While a peak temperature increase uncertainty of 20% associated with the modeling of medium-sized vasculature might be smaller than the uncertainty associated with the tissue perfusion parameters and thermoregulation (on the order of 30% [3]), it should be noted that the uncertainty in the temperature increase elsewhere – potentially in thermally sensitive tissues – can be much larger, and that only a single, illustrative MRI exposure scenario has currently been studied.

Future investigations of more exposure scenarios and more realistic modeling of the impact of the thermal vasculature (e.g., based on the DIVA model [7] that couples 1D convective vascular tree thermal simulations with 3D thermal modelling) must be performed.