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A MULTISCALE FINITE ELEMENT MODEL OF THE ELECTRICAL PROPERTIES OF THYROID TISSUE

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Summary: Thyroidectomy is a surgical procedure which is associated with several complications that can occur due to unintended damage of the parathyroid glands. One of the possible tools that could guide clinicians during the surgery is a probe exploiting the Electrical Impedance Spectroscopy (EIS) technique. This has previously been used to differentiate between tissues in their healthy and pathological states, based on the effects of the cellular structure on the flow of alternating current at different frequencies. Bearing in mind the evident differences in the microstructure between thyroid and parathyroid tissue, it is anticipated this will considerably affect the respective tissue electrical properties, allowing their differentiation. A finite element-based multiscale model is proposed in order to gain a better understanding of the structure's characteristics' effect on the electrical properties of thyroid tissue and to suggest potential improvements to the thyroidectomy surgical technique. Due to the capacitive nature of cellular membrane, biological structures exhibit a frequency-dependent decrease in impedance occurring around the kHz-MHz region. To overcome the computational resources limitations arising for the need to include these small structures, a multiscale modelling approach is implemented to study the electrical behaviour of thyroid tissue where three levels of complexity can be distinguished: i) thyrocyte (cellular scale), ii) follicle and iii) tissue scale level, the latter representing in vivo EIS measurements with a tetrapolar EIS probe. The lower-level real transfer impedance results are assigned to a higher-level model in the form of material properties calculated for each frequency. Several input parameters, comprising geometrical variability, different organisation of the structures and material properties uncertainties, have been investigated and the outcomes compared to clinical data. The computational modelling framework was created using Ansys® Mechanical APDL with quasistatic time-harmonic electric simulation. Of the geometrical parameters of the thyroid tissue structure studied, the sizes of the thyrocytes and follicles have the most significant impact on the impedance at frequencies below 10kHz, as well as on the shape of the dispersion. The best agreement between the theoretical and measured spectra has been observed for models with follicle size in the range 100-150 µm. Additionally, comparing the structured and random arrangement of follicles indicates that the organisation of these structures in thyroid tissue has a little effect on the resultant impedance, if the volumetric ratio of the model compartments is kept constant. The proposed modelling pipeline will be adjusted to the requirements of parathyroid tissue which exhibits more compact cellular structure compared to the thyroid gland. The ultimate aim is to identify differences in the theoretical EIS spectra, in order to support the clinicians in the EIS guided thyroidectomy procedure.