Quasi-static assumption in electroconvulsive therapy computational modeling

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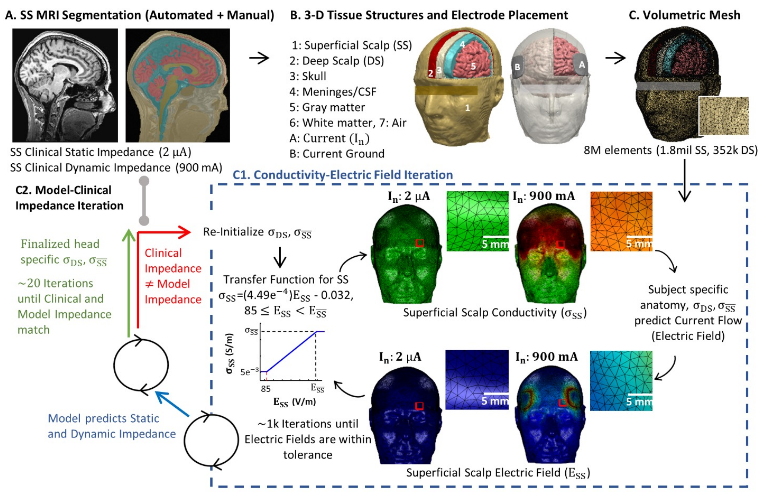
Background: Computational models of current flow during Electroconvulsive Therapy (ECT) rely on the quasi-static assumption, yet tissue impedance during ECT may be frequency specific and change adaptively to local electric field intensity.

Objectives: We systematically consider the application of the quasi-static assumption to ECT under conditions where 1) static impedance is measured before ECT and 2) during ECT when dynamic impedance is measured. We propose an update to ECT modeling accounting for frequency-dependent impedance.

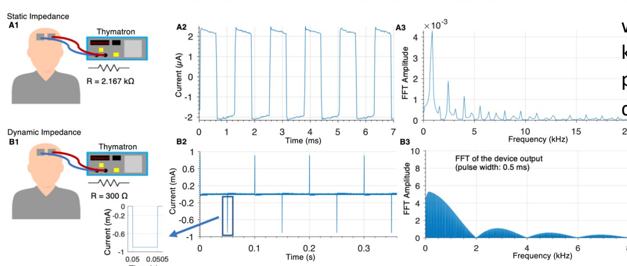
Methods: The frequency content on an ECT device output is analyzed. The ECT electrode-body impedance under low-current conditions is measured with an impedance analyzer. A framework for ECT modeling under quasi-static conditions based on a single device-specific frequency (e.g., 1 kHz) is proposed.



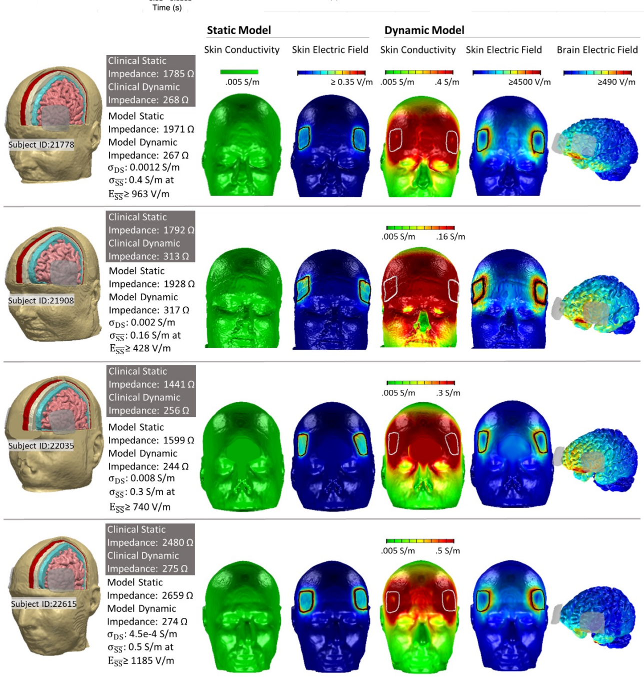
Parameters	Values
A	$5 * 10^{-3}$
B	85
C	$4.49 * 10^{-4}$
D	0.032

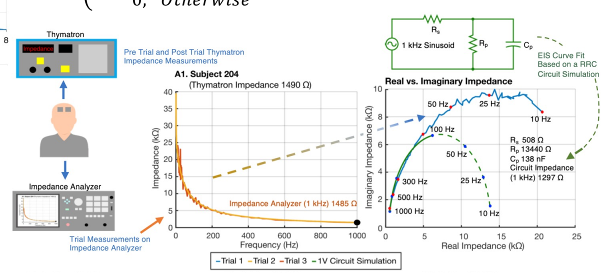
$$\sigma_{SS} = \begin{cases} A, & 0 < E_{SS} < B \\ C * E_{SS} - D, & B \le E_{SS} < E_{\overline{SS}} \\ \sigma_{\overline{SS}}, & E_{SS} \ge E_{\overline{SS}} \end{cases}$$

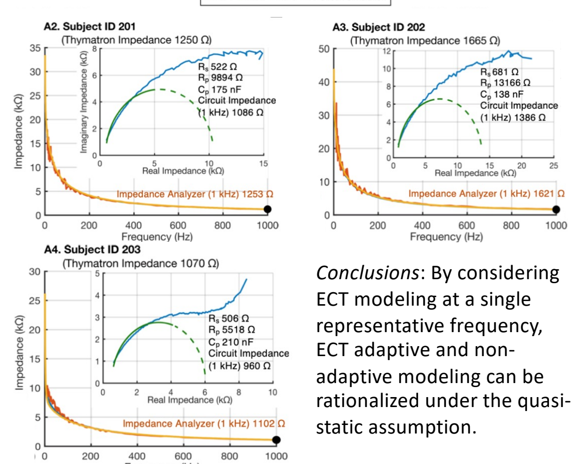
Results: Impedance using ECT electrodes under low-current is frequency dependent and subject specific, and can be approximated at >100 Hz with a subject-specific lumped parameter circuit model but at <100 Hz increased non-linearly. The ECT device uses a 2 μA 800 Hz test signal and reports a static impedance approximate 1 kHz impedance. Combined with prior evidence suggesting that conductivity does not vary significantly across ECT output frequencies at high-currents (800-900 mA), we update the adaptive pipeline for ECT modeling centered at 1 kHz frequency. Based on individual MRI and adaptive skin properties, models match static impedance (at 2 μA) and dynamic impedance (at 900 mA) of four ECT subjects.



$$x_T(t) = \begin{cases} A, & 0 < t < \Delta \\ -A, & \frac{T}{2} \le t < \frac{T}{2} + \Delta \\ 0, & Otherwise \end{cases} \qquad |Cn| = \frac{A}{\pi n} sin\left(\frac{\pi n \Delta}{T}\right)(1-(-1)^n)$$







Conclusions: By considering ECT modeling at a single representative frequency, ECT adaptive and non-adaptive modeling can be rationalized under the quasi-static assumption.