A Heat Transfer Analysis of the Cochlea During Magnetically-guided Cochlear Implant Surgery

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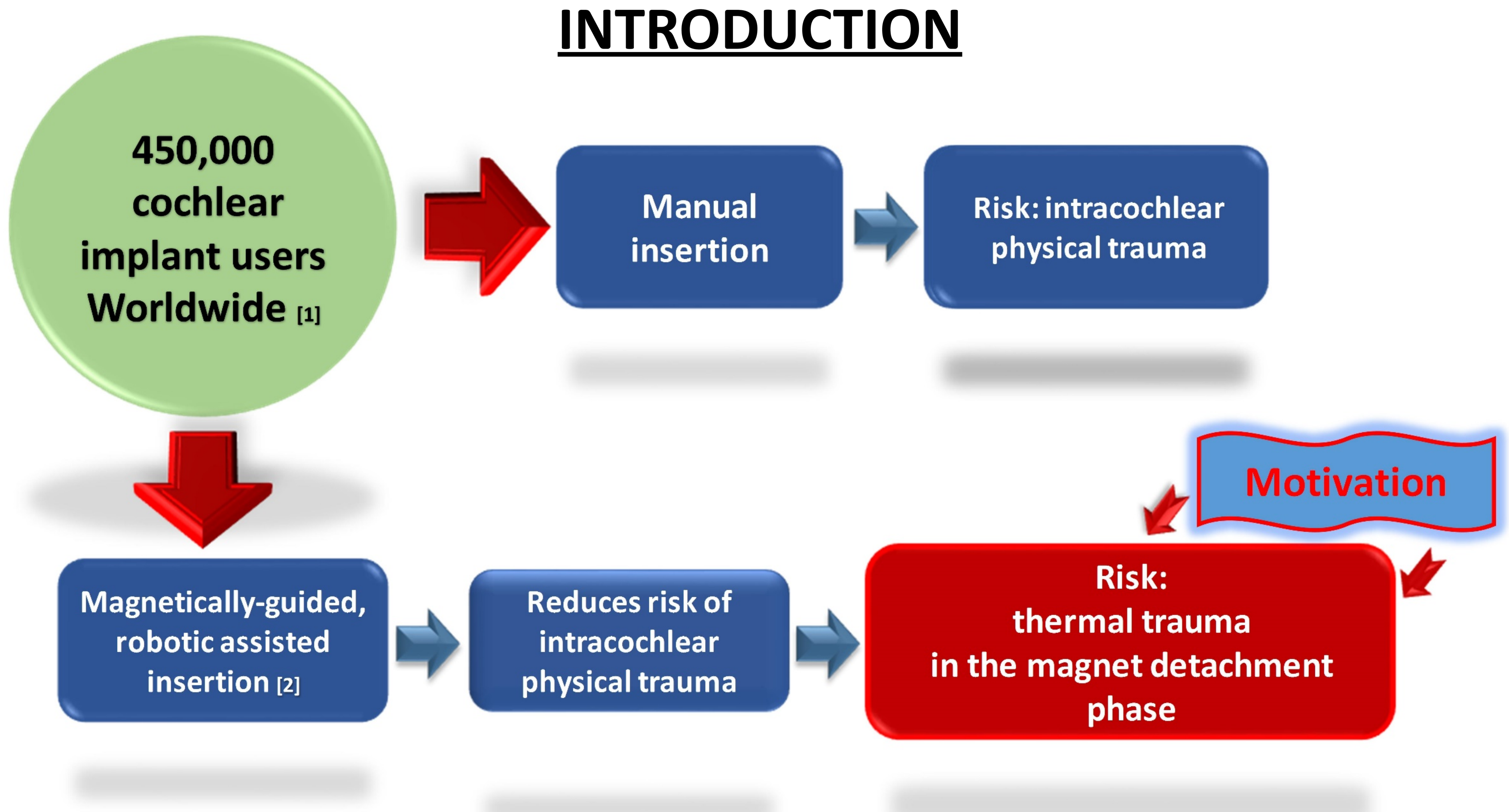
INTRODUCTION



Goals:

- ❖ Use Comsol Multiphysics 5.3a to study heat transfer within the cochlea to determine safe conditions for magnet removal.
- ❖ Verify Comsol Multiphysics 5.3a solutions for intracochlear temperature with analytical solutions.

COMPUTATIONAL METHODS

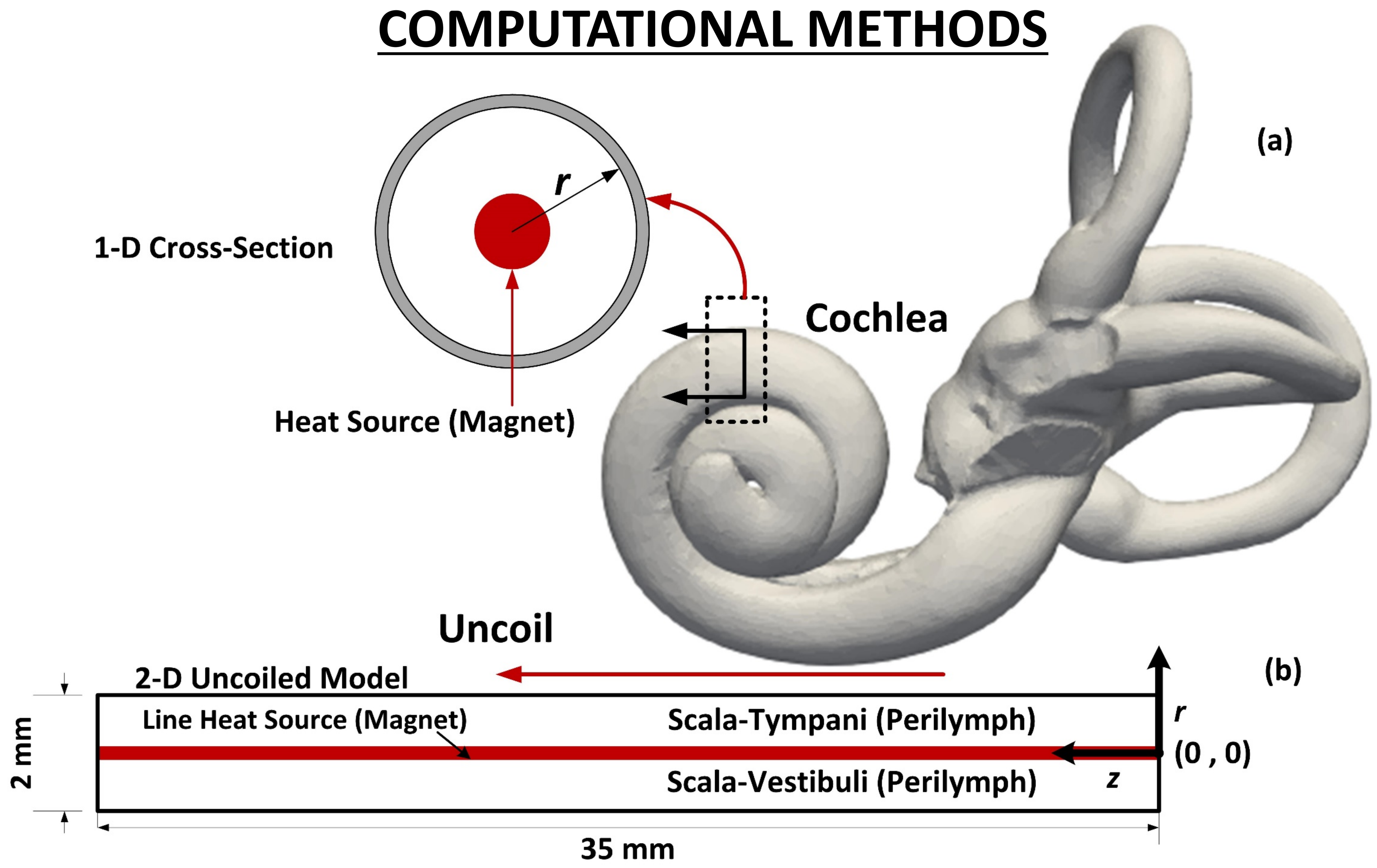


Figure 1. Simplification of a 3-D cochlea in (a) 1-D and (b) 2-D models [3].

Mathematical model (1-D, transient)

Magnet: $\alpha_1 \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_1(r,t)}{\partial r}\right) + \frac{\alpha_1}{k_1} g_0(r,t) = \frac{\partial T_1(r,t)}{\partial t}$ $\quad 0\ \text{mm} < r < 0.125\ \text{mm}$

Perilymph: $\alpha_2 \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_2(r,t)}{\partial r}\right) = \frac{\partial T_2(r,t)}{\partial t}$ $\quad 0.125\ \text{mm} < r < 1\ \text{mm}$

Boundry condition: $\frac{\partial T_2(r,t)}{\partial r} = 0$ at $r = 1$ mm

Initial condition: $T_1(r,0) = 293.15$ K

Initial condition: $T_2(r,0) = 310.15$ K

Analytical solution	Numerical solution
Solution method: Green's function Programming language: MATLAB R2018a	Software: COMSOL Multiphysics 5.3a Physics: Heat transfer in solids Study: Time dependent

RESULTS

Thermal damage threshold of in-vivo tissues depends on:

- ❖ type of tissue
- ❖ temperature (***T***)
- ❖ heat source exposure time (***t***)

For ear tissues: ***T***= 316 K and ***t*** = 114 s [4].

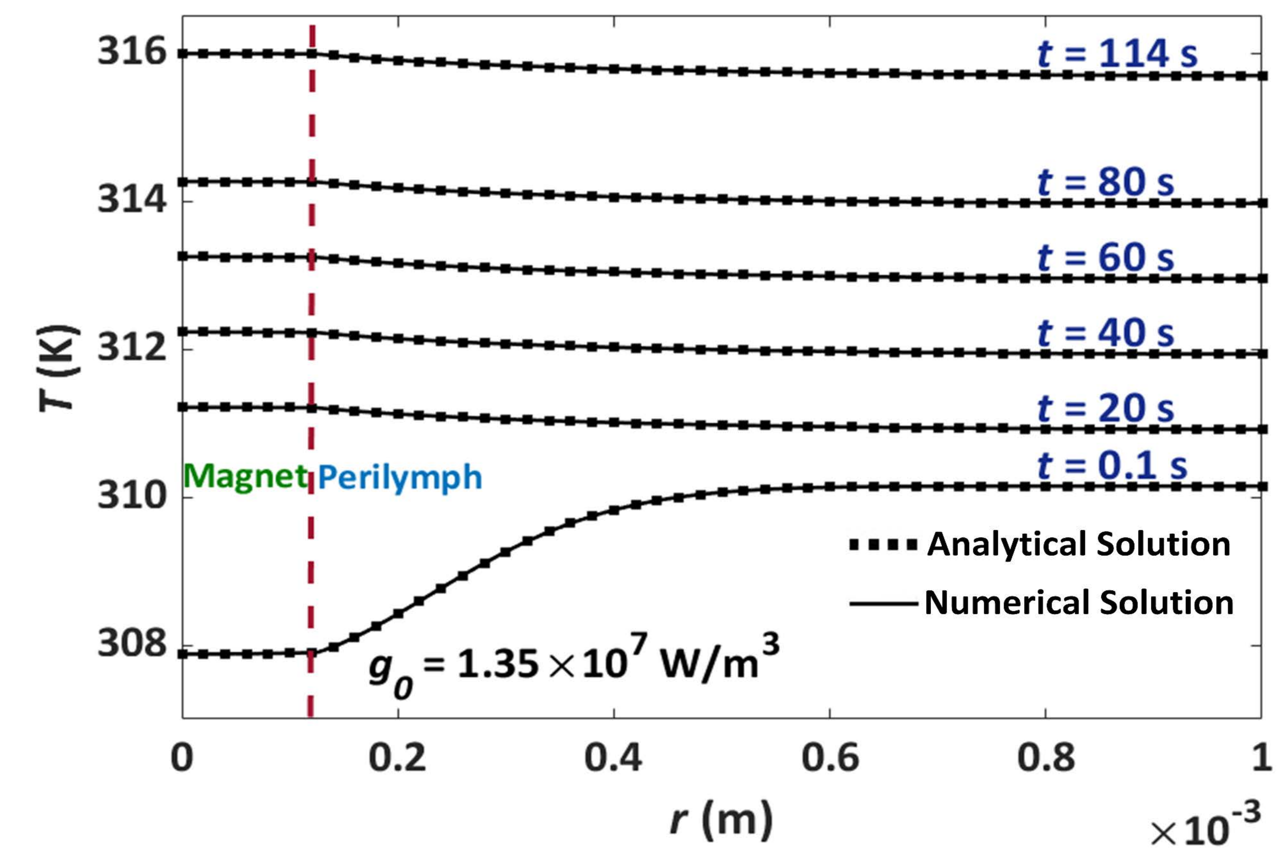


Figure 2. Transient temperature (***T***) along the cochlea radius (***r***).

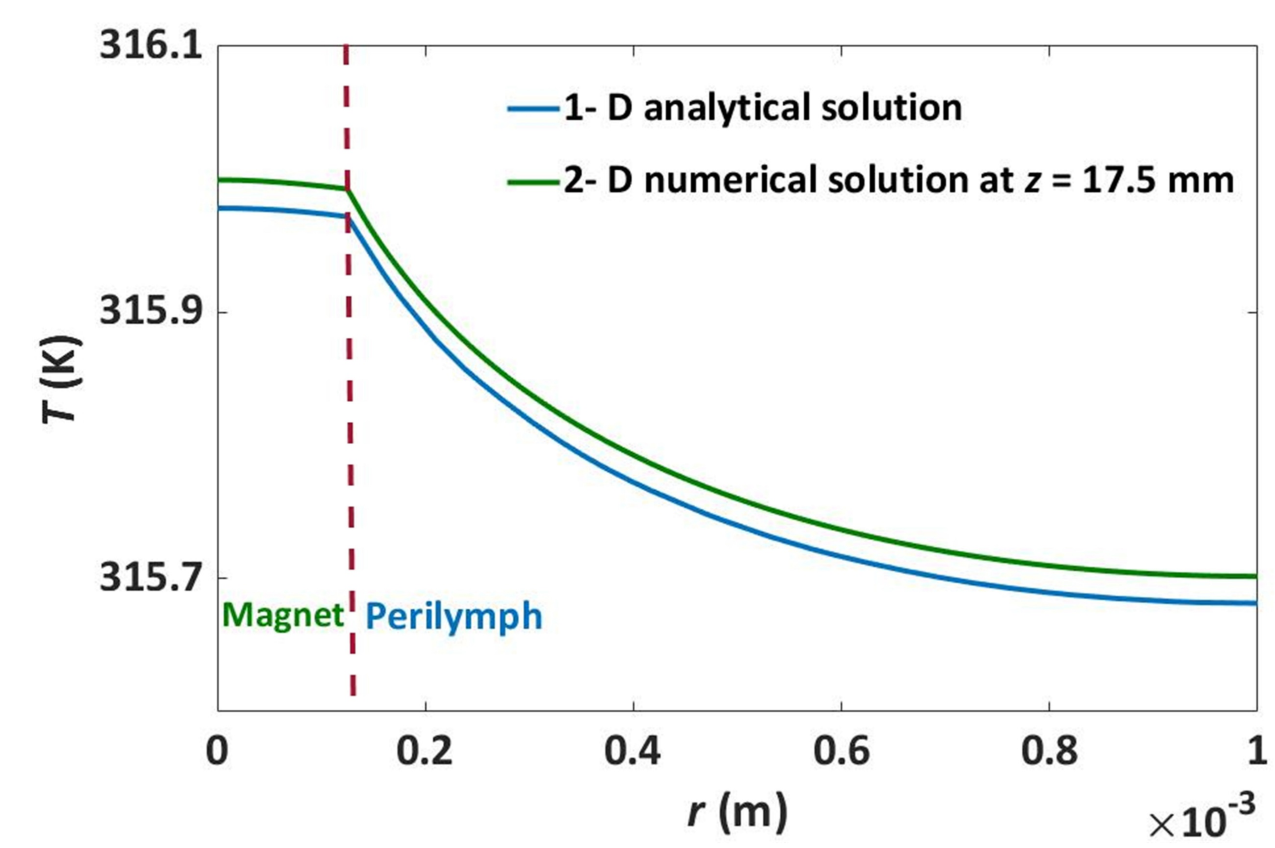


Figure 3. 1-D model validation of the 2-D numerical model in the mid-cochlea cross-section, z = 17.5 mm.

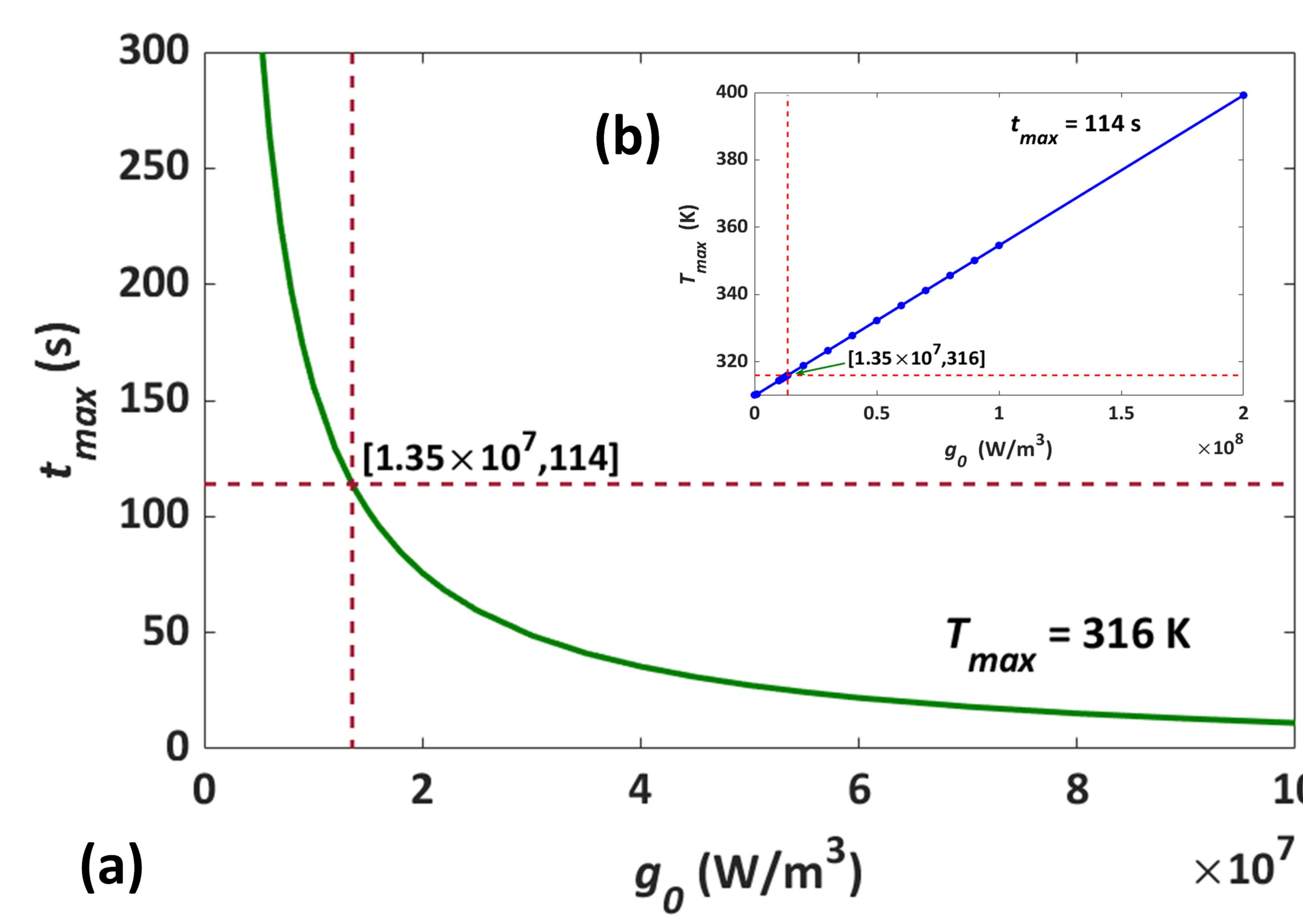


Figure 4. (a) Maximum operation time (t_{max}) as a function of power input (g_0) for a safe temperature of 316 K. (b) Maximum temperature (T_{max}) as a function of power input (g_0) for an exposure time of 114 s.

CONCLUSIONS

- ❖ The maximum temperature difference between the analytical and numerical solutions is less than 2% (Figs. 2 and 3).
- ❖ Maximum safe allowable power input for magnet detachment from cochlear implant is 1.35×10^7 W/m³ (Fig. 4).
- ❖ These results (and others) will eventually help assess the accuracy of a complex 3-D transient heat transfer model of the cochlea.

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