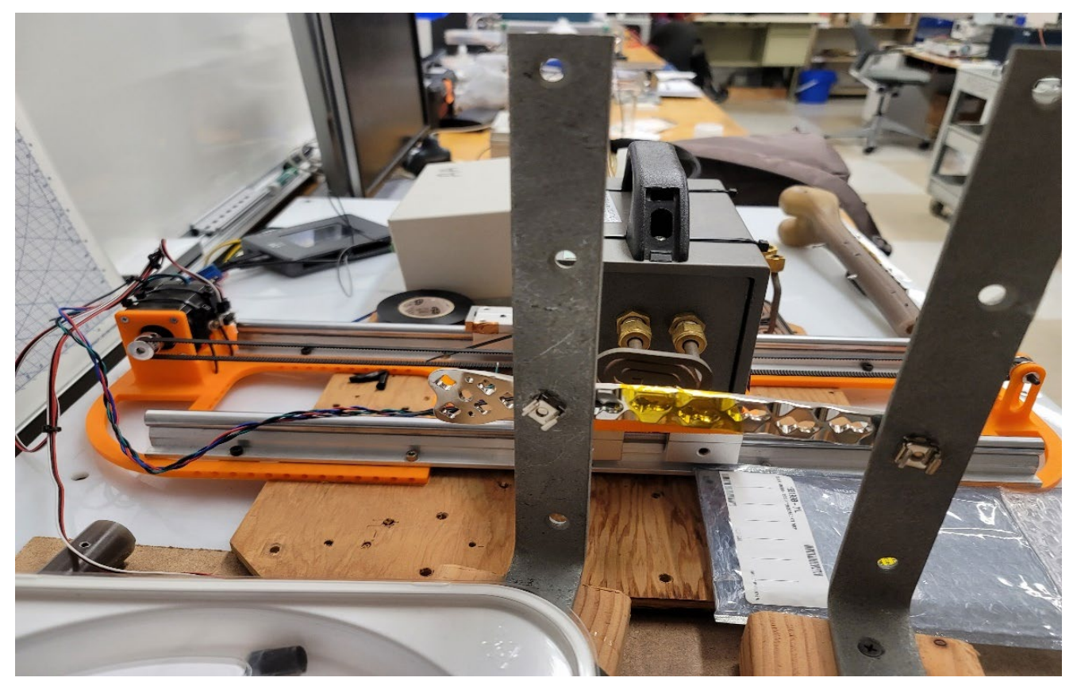
Research Experiences for Teachers

The Power of Heat: Exploring Induction Heating for Metal Biofilm Eradication



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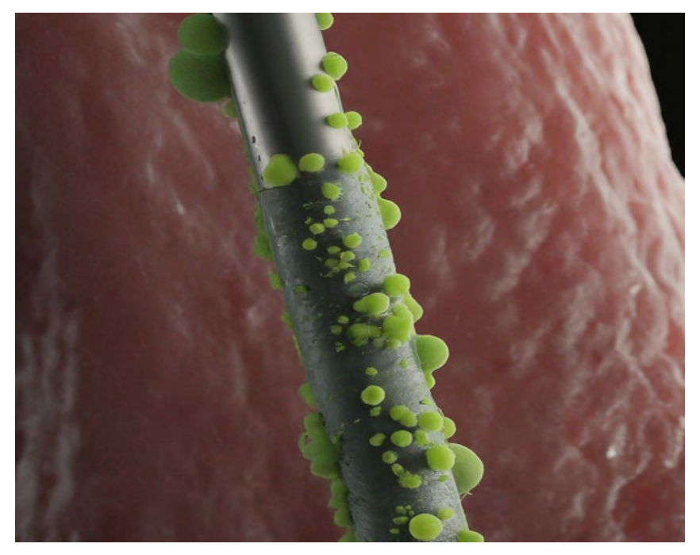
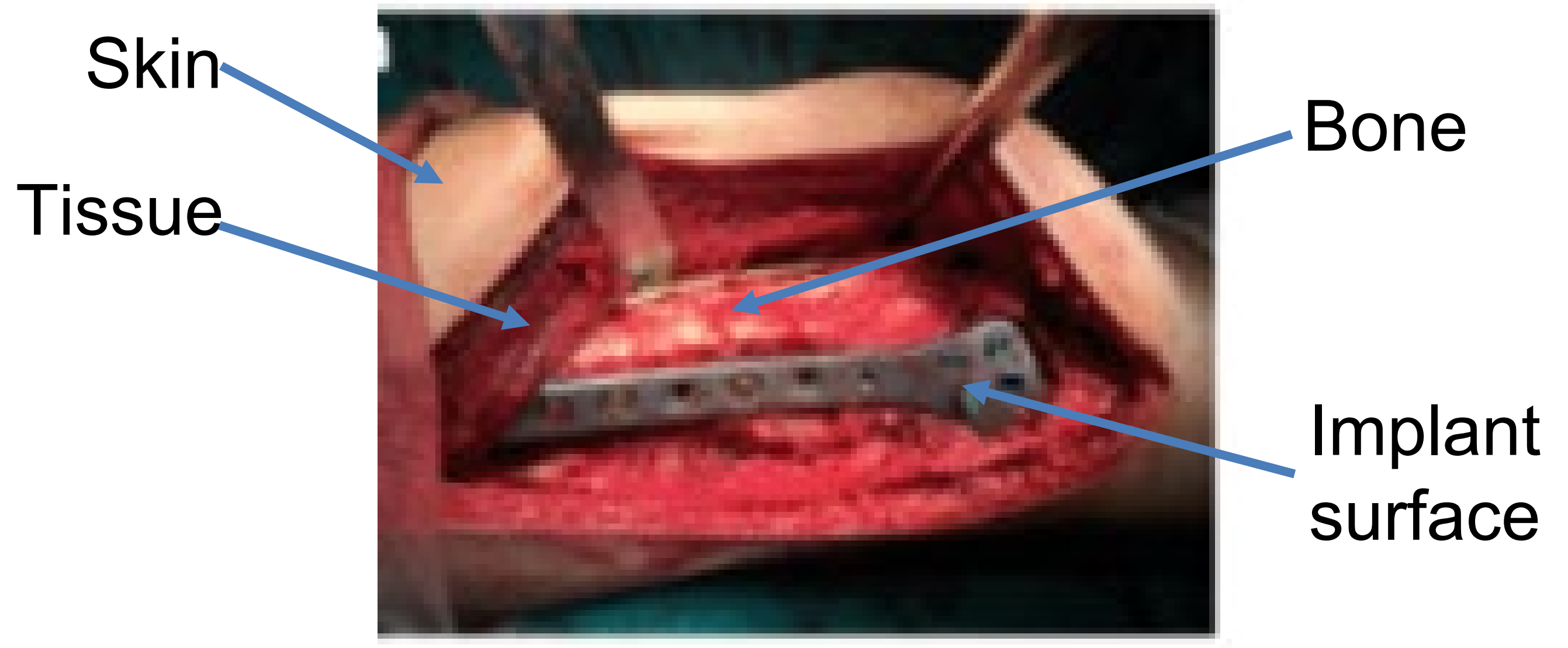
Objective



To investigate the safety and effectiveness of induction heating for treating biofilm on metal fracture fixation plates.

Rationale

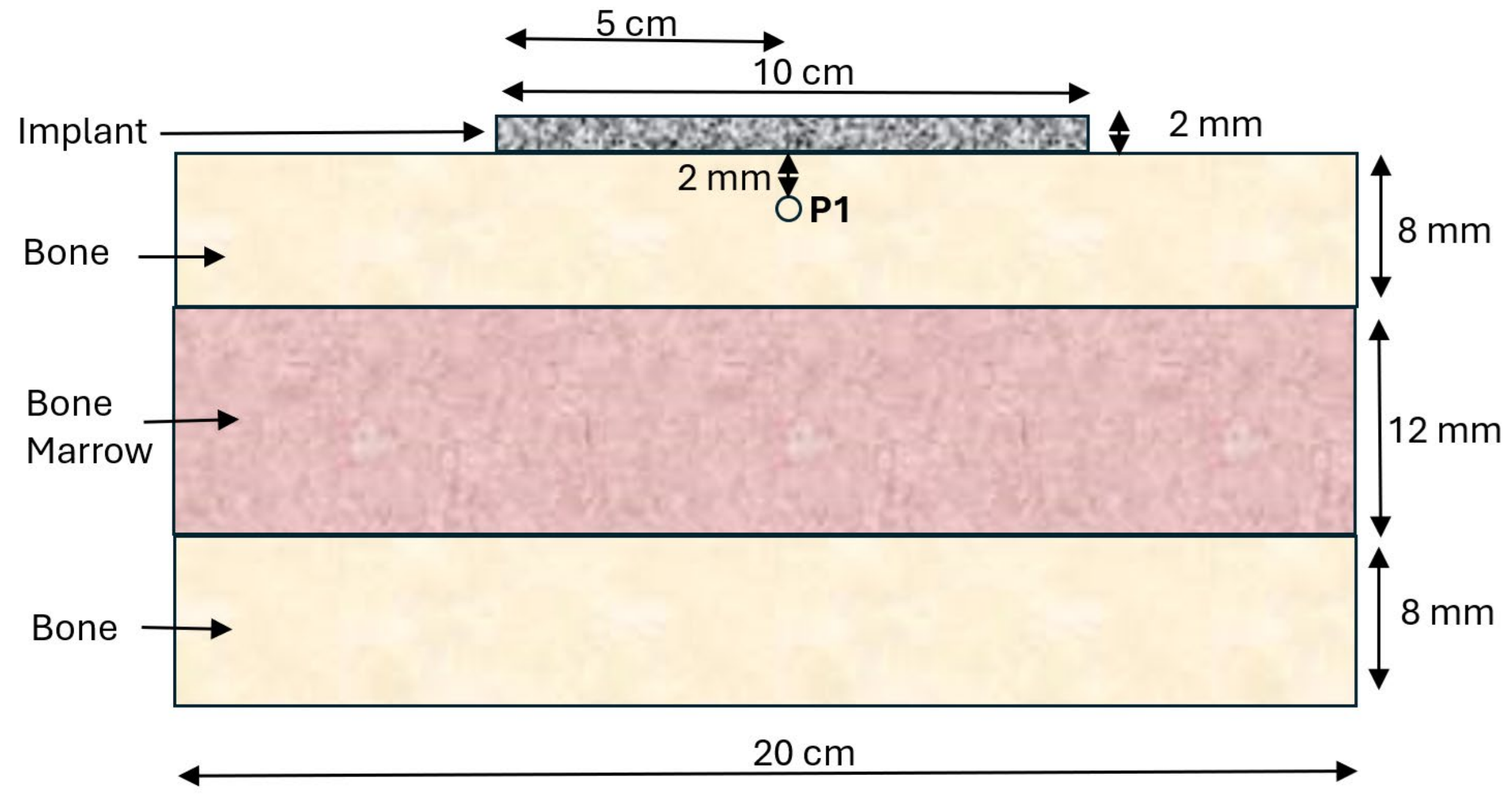
Biofilms are intricate microbial communities embedded within a self-produced protective matrix known as extracellular polymeric substance (EPS). Composed of diverse bacterial species, including Staphylococcus, Pseudomonas, and Enterococcus, these communities exhibit enhanced resistance to external threats due to the EPS shield. Biofilm formation on medical implants like fracture fixation plates can lead to infections and implant failure. Traditional antibiotic treatments often prove ineffective against these resilient bacterial communities. The current standard treatment for biofilm on fracture fixation devices involves tissue debridement, the removal of dead or damaged tissue, and pulsed lavage, a process of irrigating the wound with a pulsating fluid to cleanse it. Induction heating, specifically utilizing alternating magnetic fields (AMF) or intermittent alternating magnetic fields (iAMF), offers a promising alternative. By generating heat directly within the implant, these methods demonstrate potential as a surgical solution for biofilm eradication.



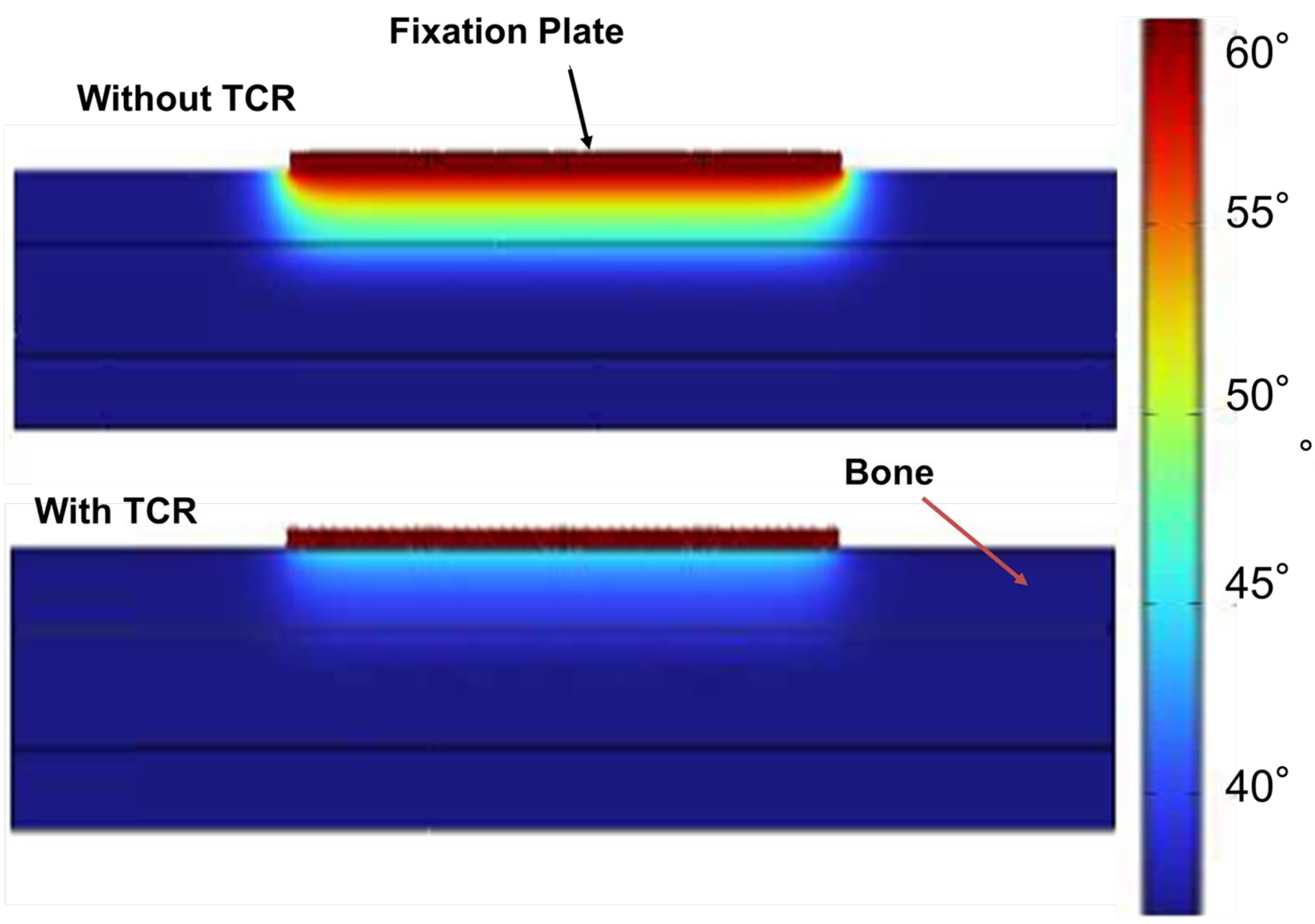
The fracture fixation plate is fixed on the outside of the femur. The presence of air gaps at the implant-bone interface significantly reduces thermal conductivity, resulting in a substantial thermal contact resistance (TCR) that impedes heat transfer between the two components. Lu et al. *Journal of Orthopedic Surgery and Research.* (2020) 15:144

Methods

This study employed COMSOL Multiphysics® software to predict temperature and thermal damage in the bone for a given implant temperature. A simplified 2D model (below) was used for the simulation. The cut line occurred at P1 (2 mm below the implant bone interface. Thermal contact resistance (TCR) that occurs in the air gap between the fracture fixation plate and bone was explored. TCR was modelled as a contact pair.

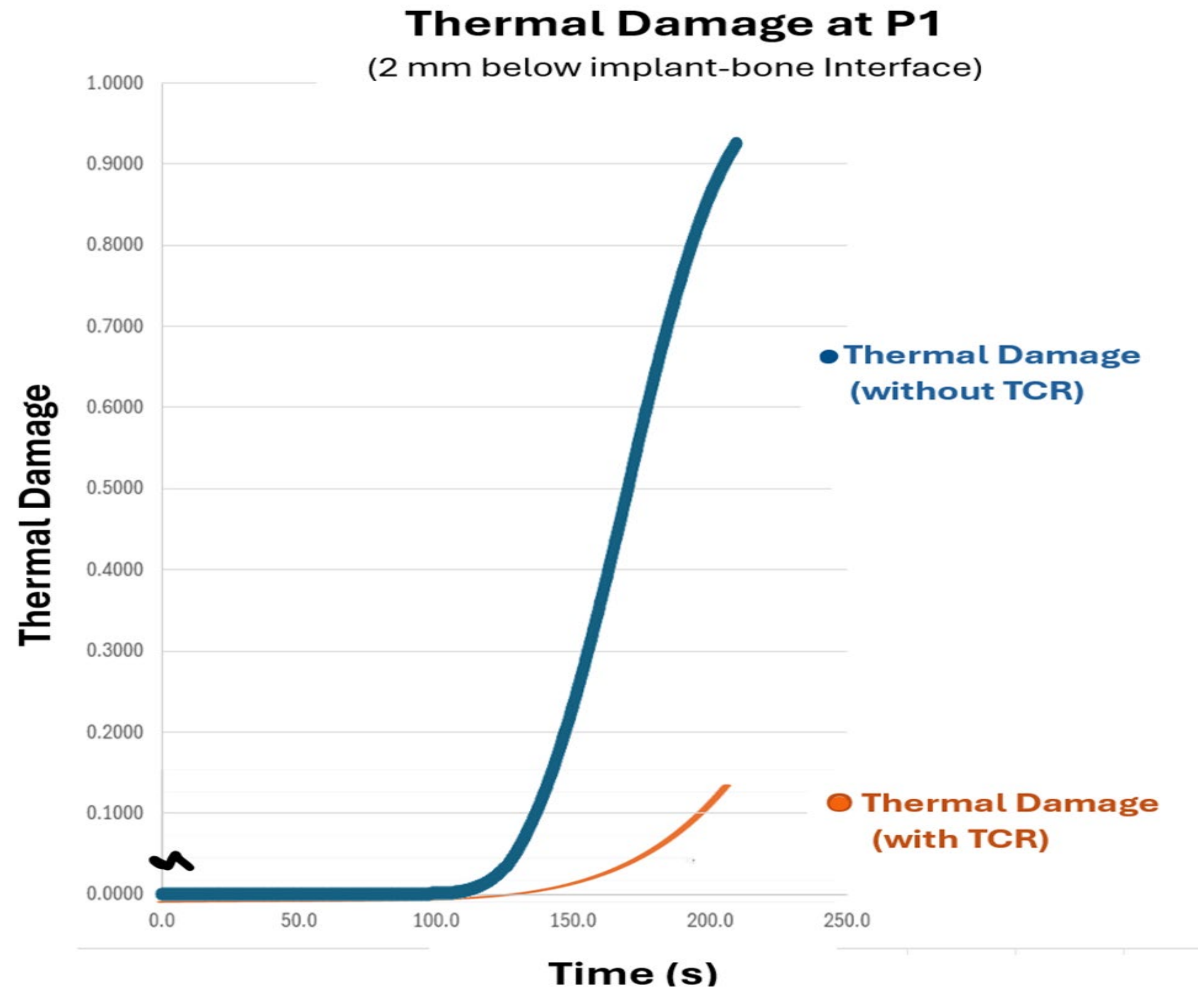


Impact of TCR on Temperature Distribution in the Bone



The image above shows that higher temperatures will be present in the thermal fracture device and the nearby bone and tissue when thermal contact resistance (TCR) is not present. However, the bottom image shows that cooler temperatures will result when there is thermal contact resistance (TCR).

Thermal Damage at P1 (2 mm below the implant bone interface)



Without thermal contact resistance (TCR) the thermal damage at location P1 approaches the highest level (1.0) at approximately 3.5 min. (210 sec); however, with TCR, the maximum level of thermal damage only reaches (0.0003), which is merely approximated on the graph above to avoid showing it as a straight line with the given scale.

Implications

The extent of thermal damage to tissue is directly related to the duration of heat exposure. When applying induction heating for biofilm eradication, careful consideration of several critical factors is essential. These include the proximity to the heat source, the intensity of the heat generated, the duration of heating, the compatibility of the implant material, the surface texture of the implant, any applied coatings, and the implant's overall shape and size.

References

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- Prasad, B., et al. (2022). International Journal of Hyperthermia, 39(1), 713-714.
- Schoenmakers, J. W. A., et al. (2020). European Journal of Nuclear Medicine and Molecular Imaging, 48, 757-767.

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