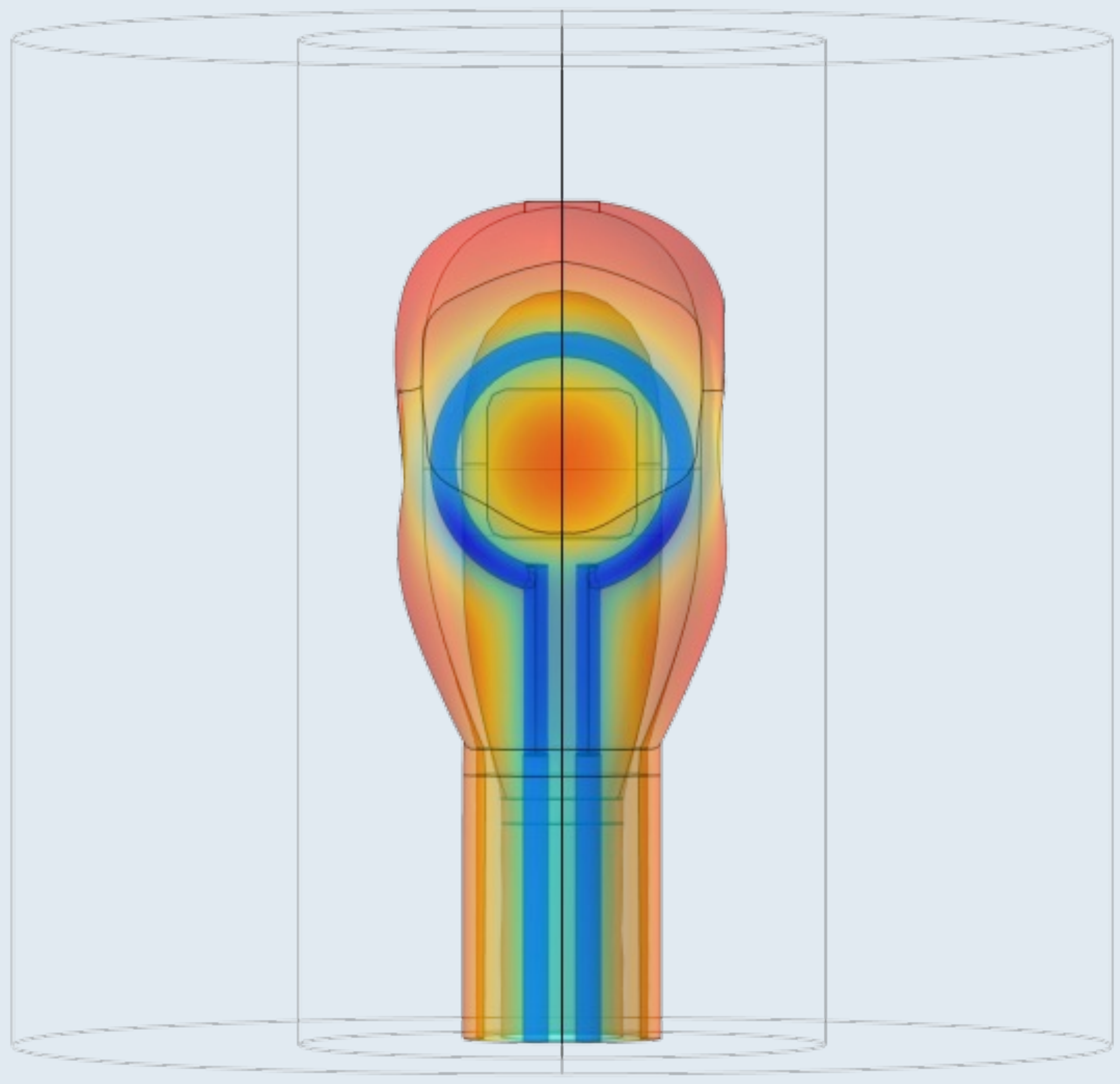

Design of a Miniaturized Cooling System for Minimally Invasive Cardiac Surgery

Enhance the reliability of ultrasound imaging in Minimally Invasive Cardiac Surgery by mastering the thermal management of Trans-Esophageal Echocardiographic (TEE) probes.

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Introduction & Goals

Minimally Invasive Surgery (MIS) for cardiac procedures is a valid alternative to open-heart surgeries, allowing for a faster post-operative recovery [1]. Nowadays, during MIS interventions, fluoroscopic (i.e., x-rays-based technique) and ultrasound (US) images, specifically using a Trans-Esophageal Echocardiographic (TEE) probe, are relied on simultaneously [2]. However, TEE probes overheat due to the Joule effect, causing thermal damage to the inner walls of the esophagus.

Both in vitro and in vivo studies report that cell death is triggered by a specific range of thermal dose, which is why TEE commercial devices automatically switch off at 42.5°C [3]. Based on numerical simulations and experimental results, a significantly stable miniaturized cooling device for TEE probes is presented, thus enhancing the reliability of US images in the intraoperative scenario, as they are completely harmless to both patients and doctors.

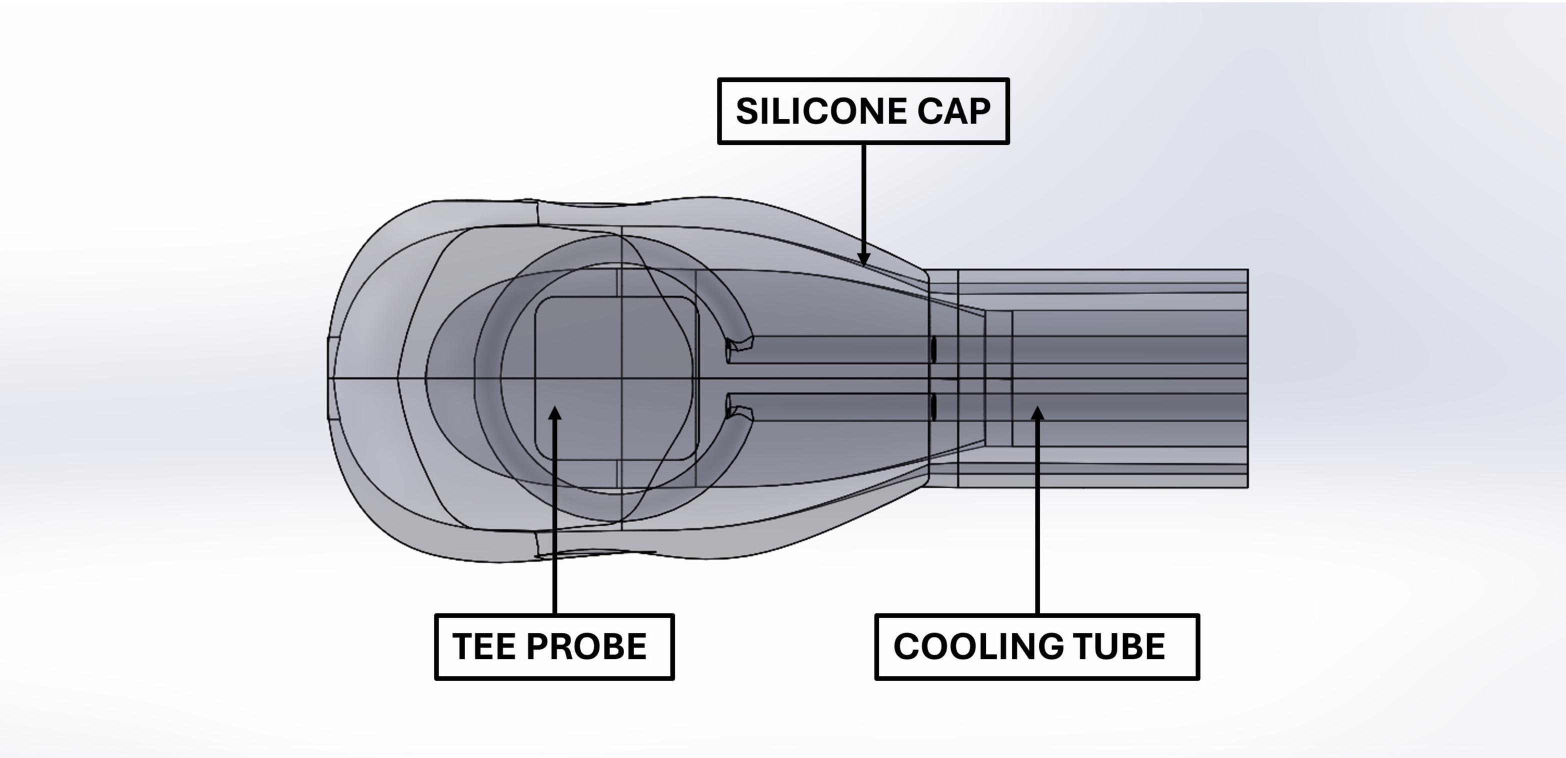

FIGURE 1. CAD representation of the cooling system design: silicone cap containing an inner tube into which water - the cooling fluid - flows at a constant temperature of 25°C.

Methodology

The proposed cooling system has the shape of a silicone cap (Figure 1).

Heat exchange phenomena - considering the endoluminal setting of the esophagus - are here combined with the study of a turbulent water flow. A dual heat transfer module is evaluated: the convection phenomenon - between the cooling fluid and the silicone cap - is modeled using Newton's law (1) while conduction - between the cap and the probe - by means of Fourier's law (2).

$$q'' = h(T_s - T_\infty) \qquad (1)$$

$$q'' = -\lambda \frac{\mathrm{dT}}{\mathrm{dx}} \qquad (2)$$

Results

The aim of these thermo-fluid dynamic simulations was to validate the mechanical design and serve as a basis for the temperature control system. Physiological conditions are also considered by inserting the probe into a hollow cylinder simulating the esophagus.

Figure 2 shows how the probe starting from 38°C reaches a safe temperature (≈37°C, physiological body temperature) in 0.5 minutes, which is an absolutely acceptable time frame, especially when compared with the duration of the surgical procedure (approximately 2h) at stake [2]. These results have been confirmed by experimental tests.

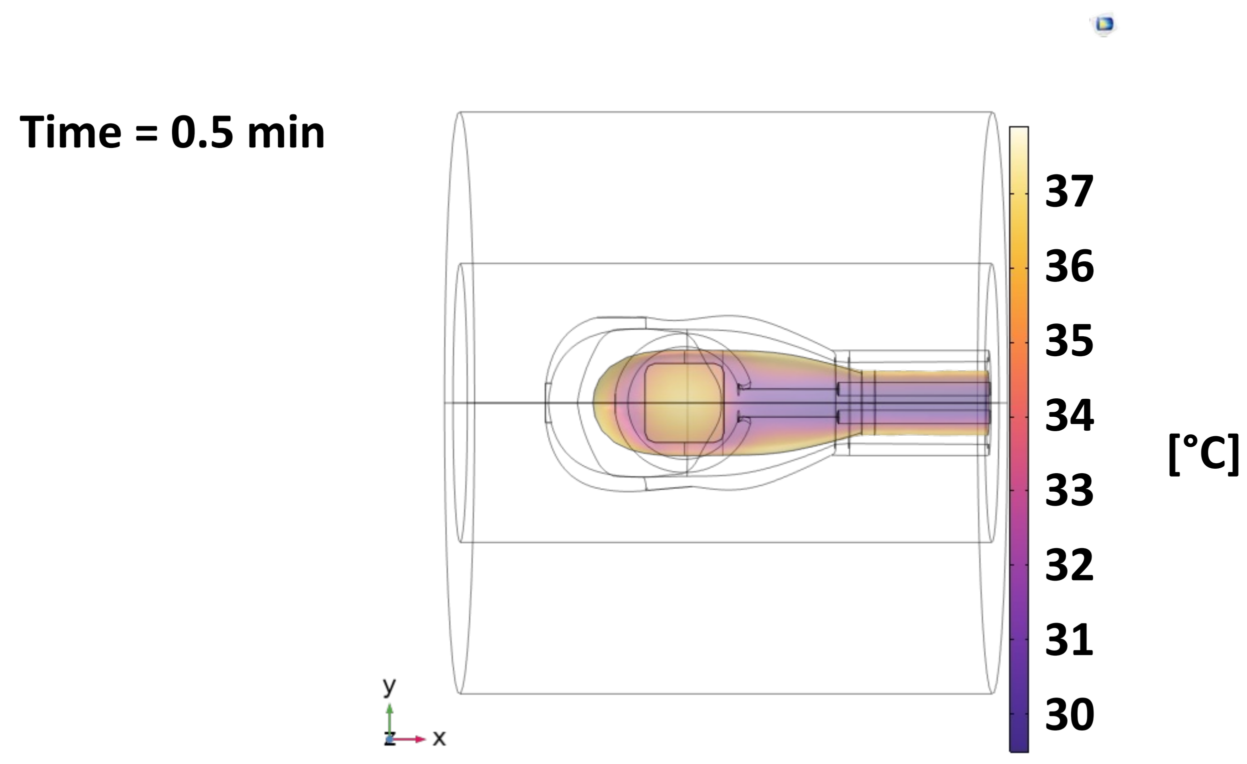

FIGURE 2. Temperature map related to the TEE probe, considering the condition where the probe starts from 38°C: it can be observed that in 0.5 minutes the cooling is effective.

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