IN VITRO EVALUATION OF THE HEAT TRANSFER IN ENDOVENOUS LASER TREATMENTS

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Abstract. *The endovenous laser treatment (EVLT) of varicose veins has been widely adopted based on its good results, but its mechanism of action is yet barely known. In this work an experimental study of the heat transfer within the vein during an endovenous laser treatment is conducted using a silicone vein model (in horizontal position) filled with bovine blood. The results showed that the heat transfer is not homogeneous along the vein perimeter and that the bubble formation may play a central role in the energy distribution within the vein. The heat flux to the upper part of the vessel wall may be more than 15 times higher than the heat flux to the bottom part. This non homogeneity of the heat flux may help in explaining the recanalization problems still found in some patients submitted to the endovenous laser treatment.*

Keywords*: endovenous laser treatment, temperature measurement, heat flux non homogeneity, recanalization.*

1. INTRODUCTION

The traditional procedure of vein stripping of varicose veins is being gradually replaced by thermal treatments that aim to cause a thermal damage at the inner layer of the vein walls (*intima*). Among the available thermal techniques the endovenous laser treatment (EVLT) presents good short term results and acceptable long term recanalization rates (Medeiros, 2006; Tursie et al., 2010). Laser procedures use the absorption of light by the medium to generate heat, leading to thermal damage of a target tissue. In the venous treatment case, without draining techniques and in orthostatic position, the laser beam is submerged in blood. Then, the laser beam propagates basically through a medium composed by a fluid (plasma) with a suspension of solid particles (hemoglobin cells). The energy absorbed by the medium generates heat that is dissipated within the vein, damaging the surrounding tissue if a high enough temperature is reached.

The detailed mechanism of action of endovenous laser treatments is not well known (Van der Geld et al., 2010; Fan and Anderson, 2008; Disselhoff et al. 2008). The laser energy is absorbed by the fluid and solid phases of the blood, bubbles formed by steam and non-condensable gases are observed, direct contact of the laser tip with the vein walls may occur if the laser is not centered and direct laser incidence of the laser on the walls will occur whenever the vein is not filled with blood. The relative importance of conduction, convection and radiation in this thermal therapy are not clear. The non-uniformity of the vein diameter imposes an additional difficulty in analyzing this problem. Some hypotheses have been proposed but little experimental evidences have been produced to support each hypothesis (Fan and Anderson, 2008).

To help in bringing some light to this problem, in the present work a silicone vein model filled with bovine blood was instrumented with temperature sensors and the EVLT procedure was simulated. This simple apparatus can produce valuable information because the non-uniformities of the vein geometry are suppressed allowing for a precise determination of reference temperatures during the procedure. The results point at an important non homogeneity of the heat distribution along the vein perimeter. This non homogeneity may help in explaining the recanalization problems still found in some patients submitted to the endovenous laser treatment.

2. MATERIALS AND METHODS

A schematic representation of the experimental setup is shown in Fig.1. The workbench consists of a silicone vein model with 8 mm diameter and 200 mm long where fast response thermistors (*Semitec USA - 223Fμ3122-07U015)* were used to measure the temperature at the outer wall at four positions distributed around its perimeter. The same configuration is repeated at four sections along the model length with 15 mm of distance between each measurement section. Then, a total of 16 sensors are used at the outer wall of the model.

The vein model is connected to tubing systems that allow the model to be filled with bovine blood without air bubbles and also permit the introduction of the temperature sensing catheter. The bovine blood was collected from a local food industry and was conserved prior to use in a recipient with heparin to avoid coagulation.

A special temperature sensing catheter (Biokyra Pesquisa & Desenvolvimento, Florianópolis - SC), also shown in Fig.1, was built to measure the inner wall temperature at a variety of angles. It is composed by a 4 mm (12 F) multi-lumen PTFE shield with (with four lumens), carrying three NiTi tubes with 0.35 mm of inner diameter in the outer lumens and the laser fiber in the central lumen. The three metallic tubes expand radially when out of the shield forming a structure that centralizes the laser fiber. Each metallic tube has a thermistor in its tip that will be in contact with the outer inner wall of the model during the procedure. The laser system used was an 810 nm Synnus Novadiode 30 diode-laser, *with* a 600 μm medical optical fiber.

The experimental method consisted of the following steps:

1) To insert the catheter at the vein model though the tubing system (model in horizontal position);
2) To fill the vein model with the bovine blood taking care to remove the air bubbles;
3) To perform the EVLT (constant beam laser at 15W) while the catheter is pulled with a constant velocity (5 mm/s).
4) To rotate the catheter in 30° and to repeat the test. This procedure is performed until the initial position is achieved again, providing temperature measurements of the inner wall in 12 different points distributed around the vessel perimeter.

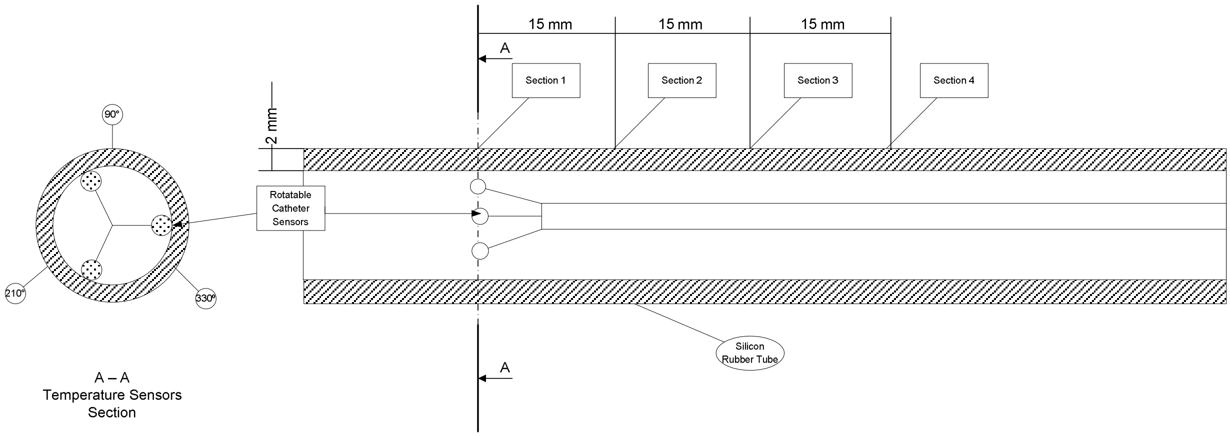


Figure 1. Experimental setup showing the vessel model, temperature sensors positions at the outer wall and the temperature sensing catheter.

3. RESULTS AND DISCUSSION

During the tests the generation of bubbles is always important. Small bubbles are formed at the fiber tip (as reported by Proebstle et al., 2002) at a rate that depends on the laser intensity. These bubbles agglomerate downstream forming larger bubbles that occupy a certain amount of the vessel intraluminal volume as can be seen in Fig. 2. The bubbles are formed not only by steam but also by non-condensable gases that accumulate during the process. The movement of these bubbles is controlled by buoyancy.

The maximum temperatures achieved by the temperature sensing catheter are shown in Fig. 3 (90° corresponds to the upper part of the vessel). Higher temperatures are observed at the upper part of the vessel (70°C to 160°C), while quite low temperatures are observed at the bottom part (30°C to 50°C). This important result is an indication that the procedure is not homogeneous, with the upper part being much more affected by the laser energy than the bottom part. Then, near half of the vessel perimeter does not achieve the required temperatures for the procedure to be effective (70°C – Van den Bos et al., 2009), i.e., to cause a permanent thermal damage to the intima.

A possible explanation for this behavior is that the laser energy is mainly absorbed by the blood near the catheter tip, creating a hot blood region and bubbles. The bubbles and also the hot blood are driven by buoyancy to the upper part of the vessel heating that region by surface convection. On the other hand, at the bottom part of the vessel a layer of cold blood is formed, insulating the vessel wall. Since the thermal conductivity of the silicon model is not able to homogenize the angular temperature gradients, the distribution of Fig. 3 is obtained.

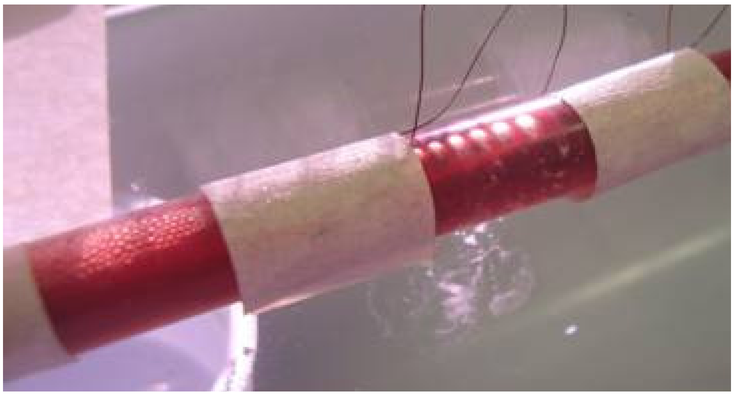


Figure 2. Small bubbles formation at the tip of the laser fiber (left side)
and downstream aglomeration into larger bubbles (right side).

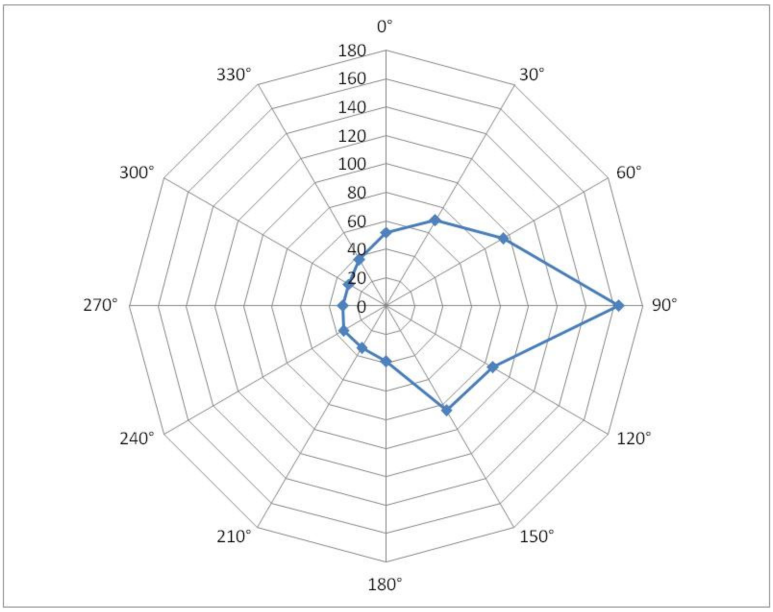
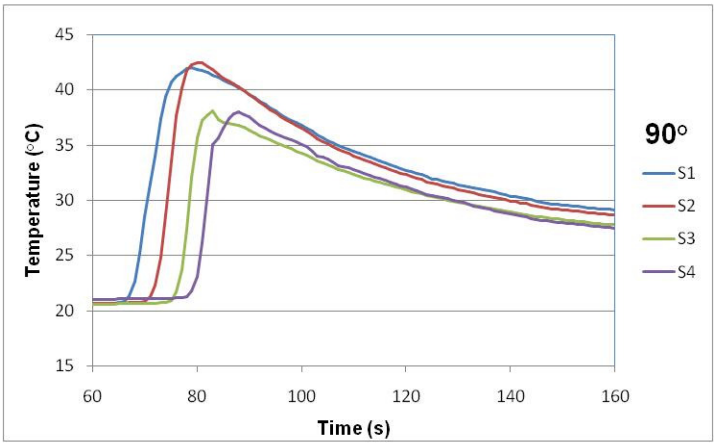


Figure 3. Maximum temperatures (radial coordinate in °C) measured at the inner wall of the vessel as a function of the angular orientation (angular coordinates). 90° corresponds to the upper part of the vessel.

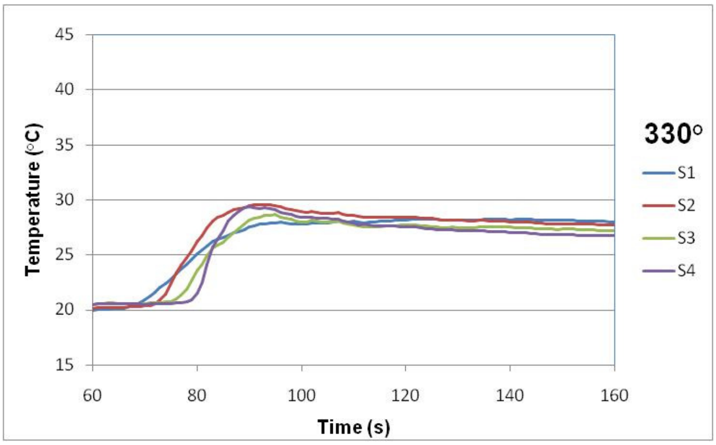
Figure 4 shows the temperature histories during a typical test for the outer wall sensors at two specific positions (90° - upward direction, and 330° - a typical bottomward direction). The temperature peak is associated to the moment when the fiber tip is closer to the measurement point. Again the higher temperatures are achieved for the sensors at the top of the vessel (temperatures around 40°C) while lower temperatures are observed at the other sensors located at the bottom part of the vessel (temperatures around 30°C).

The radial conduction heat flux through the wall at an specific angular orientation, q_k, can be approximated by $q_k = \Delta T/R_k$, where ΔT is the radial temperature difference between the outer and inner surface of the vessel wall and R_k is the conduction thermal resistance, that can be assumed to be a constant for any angular orientation. Then, the relative heat flux between two specific angular orientations can be approximated by $q_{k,1}/q_{k,2} = \Delta T_1/\Delta T_2$. Evaluating the temperature differences with the maximum temperatures achieved at the inner and outer surfaces, the following order of magnitude can be obtained: $q_{k,90°}/q_{k,330°} \sim \Delta T_{90°}/\Delta T_{330°} = 121/7 \sim 17$. This rough approximation shows that the heat flux has indeed a preferential path to the upper direction.

This non homogeneity of the heat flux may help in explaining the recanalization problems still found in some patients submitted to the endovenous laser treatment. Since the bottom part of the vessel may not achieve the temperatures required to a permanent thermal damage these portions of the vessel wall are more prone to the recanalization process.



(a)



(b)

Figure 4. Outer wall temperature histories for 90° and 330° angular orientations for the four measurement sections (S1 to S4).

Figure 5 shows the fiber tip after a typical test. It is possible to note that blood clots were formed at the tip of the vessel. These clots are an additional absorbing/scattering medium for the laser radiation, which means that a part of the laser energy is absorbed or scattered before reaching the blood. Some carbonized clot regions are also observed, indicating that high temperatures are reached in this region, which may also explain the presence of non-condensable gases.

Figure 5. Presence of blood clots at the fiber tip after a typical test.

4. CONCLUSION

An in-vitro experimental study of the endovenous laser treatment was conducted in a silicon vein model filled with bovine blood in horizontal position. Temperatures along the inner and outer surfaces of the model were measured during the procedure with fast response thermistors and a special catheter.

The results point to an important non homogeneity of the temperatures along the vein perimeter, with the upper part of the vessel achieving higher temperatures than the bottom part. It is argued that the laser energy is mainly absorbed by the blood near the catheter tip, creating a hot blood region and bubbles that are driven by buoyancy to the upper part of the vessel, leaving a layer of cold blood at the bottom part. A preliminary analysis shows that the radial conduction heat flux to the top of the vessel is typically more than 15 times higher than the heat flux to an angular orientation directed to the bottom part of the vessel. This non homogeneity of the heat flux may help in explaining the recanalization problems still found in some patients submitted to the endovenous laser treatment.

5. AKNOWLEDGMENTS

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7. RESPONSIBILITY NOTICE

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