

## The heat-pipe resembling action of boiling bubbles in endovenous laser ablation

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**Abstract** Endovenous laser ablation (EVLA) produces boiling bubbles emerging from pores within the hot fiber tip and traveling over a distal length of about 20 mm before condensing. This evaporation-condensation mechanism makes the vein act like a heat pipe, where very efficient heat transport maintains a constant temperature, the saturation temperature of 100°C, over the volume where these non-condensing bubbles exist. During EVLA the above-mentioned observations indicate that a venous cylindrical volume with a length of about 20 mm is kept at 100°C. Pullback velocities of a few mm/s then cause at least the upper part of the treated vein wall to remain close to 100°C for a time sufficient to cause irreversible injury. In conclusion, we propose that the mechanism of action of boiling bubbles during EVLA is an efficient heat-pipe resembling way of heating of the vein wall.

**Keywords** Phlebology · Endovenous laser ablation · Boiling bubbles · Heat pipe function of treated vein

Endovenous laser ablation (EVLA) for the management of saphenous varicosities has a very high success rate with

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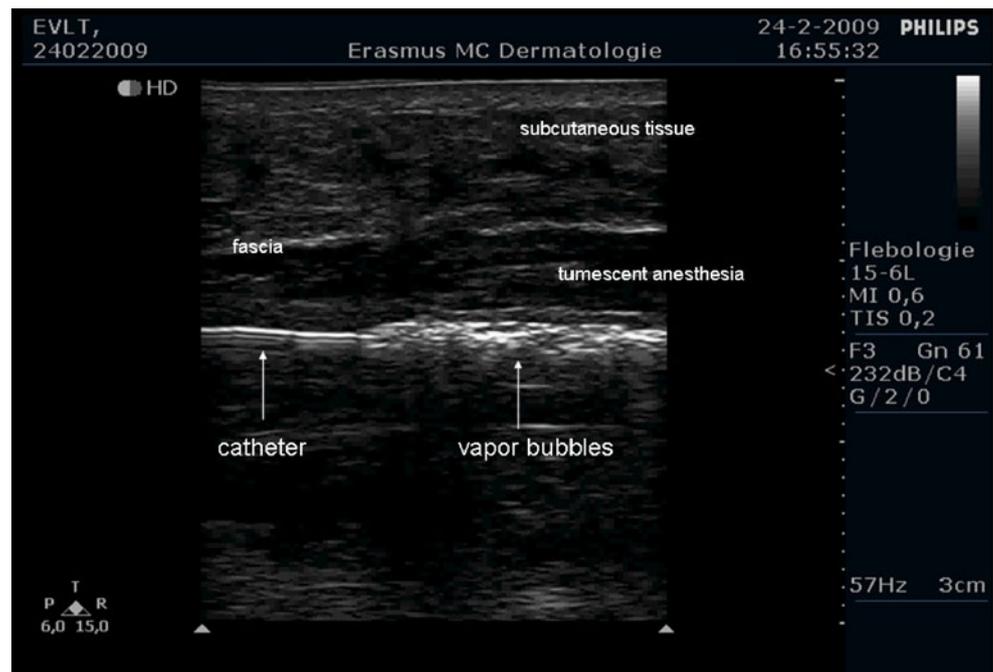
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minimal complications [1]. Nevertheless, the exact mechanism of action is still under debate. Four EVLA mechanisms to injure the vein wall have been proposed. First, the optical-thermal response to scattered laser light [2]. Second, the response to heat diffused from the hot fiber tip [3]. These tips may reach temperatures of over 800°C [4, 5], a consequence of the strongly absorbing thin layer of black carbonized blood that is deposited on the fiber tip during EVLA [6]. Third, direct contact with the fiber tip [7, 8], contributing to vein wall perforations [9]. Fourth, the response to condensing boiling bubbles [7, 8, 10]. This mechanism was proposed [10] but not proven to be an essential constituent of EVLA. In this Brief Report we aim to give a tutorial description of the proposed mechanism of action of boiling bubbles during EVLA.

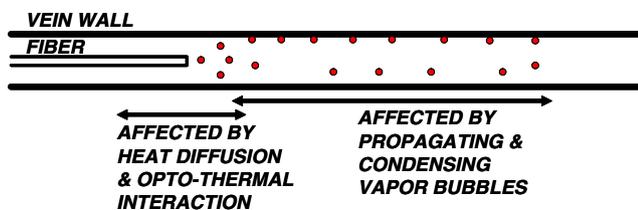
Boiling bubbles are created close to the hot fiber tip when the temperature of the blood exceeds the threshold for boiling. Most likely, these bubbles originate in tiny pores in these layers, comparable to the pores existing in walls of heated tubes, so-called heterogeneous nucleation [11]. These bubbles have been observed to travel over about 20 mm at constant volume before condensation sets in (Fig. 1). During their travel, the bubbles cause additional motion in the fluid, so-called micro-convection, which promotes heat transfer and temperature homogenization [12]. Mechanistically, the combination of creation, transport, and condensation of boiling vapor bubbles in EVLA-treated veins closely resembles the processes occurring in a so-called heat pipe [13]. Heat pipes were developed in the 1940s, are renowned for their efficiency of heat transport [14], and occur in many varieties in modern process technology [15]. Each fluid-flow and heat-transfer process in which evaporation takes place in one part and condensation in another part exhibits the main characteristics of a heat pipe.

**Fig. 1** Boiling bubbles (with vertical shadows) still visible 20 mm distal from the fiber tip during EVLA with a 1,470-nm diode laser (Ceralas E, Biolitec) at 5 W, 0.6 mm diameter fiber, about 1 mm/s pullback velocity, in a 3 mm diameter catheter



The physics of heat-pipe function is based on the fact that the boiling bubbles are in local thermodynamic equilibrium with their surroundings [16]. First, suppose theoretically that the bubble content would be superheated, i.e., have a temperature above the saturation temperature. Then, heat transfer to the surrounding liquid would occur quickly. Second, suppose that the temperature of part of the bubble would sink below the saturation temperature. Then, this part of the vapor would condense immediately. The bubble would shrink or even collapse [17, 18]. Thus, when two phases of the same component, i.e., vapor and liquid, are cohabiting the vapor phase and its immediate surroundings must have a temperature exactly equal to the saturation temperature.

Measurements in our laboratory (not shown) identified that the bubbles created during EVLA contain mainly



**Fig. 2** Cartoon of three EVLA heat-transfer mechanisms (excluding direct contact of hot fiber tip and vein wall), which are effective at different time points. The centered EVLA catheter typically has a 3 mm diameter and the tumescent anesthesia forces the vein wall to fold itself over the catheter. Heat diffusion from the hot tip and the optical-thermal interaction have their primary effect about perpendicular to the fiber near the fiber tip, over about 6 mm vein wall length (left arrow) [3]. Boiling bubbles (small spheres) reach distances of about 20 mm (right arrow)

steam. As these bubbles are non-condensing over 20 mm, the volume where they move must be at 100°C. Since bubbles move to upper parts of their enclosure, at least the upper part of the vein wall is in contact with these bubbles. Typical pullback velocities of a few mm/s cause these parts of the treated vein wall to remain close to 100°C for at least several seconds. Then, because thermal rate process theory suggests irreversible injury if a threshold temperature of 75°C occurs during 1 s, or 70°C during 10 s [19], this warrants the conclusion that the vein wall will be irreversibly injured. Figure 2 shows a cartoon of the interactions.

During EVLA, the heat-pipe resembling function of the treated vein ensures that the boiling bubbles enhance the transport of heat from the hot fiber tip to the blood volume over a distal length of about 20 mm. We emphasize that heat-loss mechanisms such as thermal conduction and convection determine the *gradient* of the temperature at e.g., the vessel wall but *not* the temperature itself.

In conclusion, we propose the mechanism of action of boiling bubbles during EVLA is a heat-pipe resembling efficient way of heating of the vein wall.

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