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Optical Device for Liquid Injection into Skin Phantoms based on Thermocavitation

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Abstract. In this work, an optical device was developed for the injection of liquids jets into skin phantoms based on the phenomenon of thermocavitation. Vapor bubbles were generated by a continuous wave laser inside a truncated elliptical cavity (12 mm major axis and 6 mm minor axis), which contains a highly absorbent solution (α=135 cm^{-1}) at the laser operating wavelength (980 nm). The cavity was designed in SolidWorks and manufactured on a 3D printer with a polymeric material. The generated bubble grows inside the cavity and later it collapses emitting an intense acoustic wave, which is concentrated in the upper part of the cavity, expelling a liquid jet at a velocity of ~85 m/s, through an exit channel (250 µm of radio and 200 µm of height). Penetration tests were performed on agar gels at a concentration of 1.0% and visualized using a fast camera (35000 fps). The maximum penetration depth was ~2.9 mm, after 6 liquid jets hit the sample.

Keywords: Thermocavitation, injection, needle free.

1 Introduction

According to the World Health Organization (WHO), it is estimated that around 12 billion injections are administered per year, and it is calculated that of all the waste (syringes/needles) generated by these activities, approximately 85% is non-hazardous waste, but they require special protocols for their correct disposal [1]. Situation that has become even more complex in recent years, caused by the global vaccination campaign against COVID-19.

Due to the above, there is a greater interest in the research and development of technology related to the generation of liquid jets for the administration of drugs

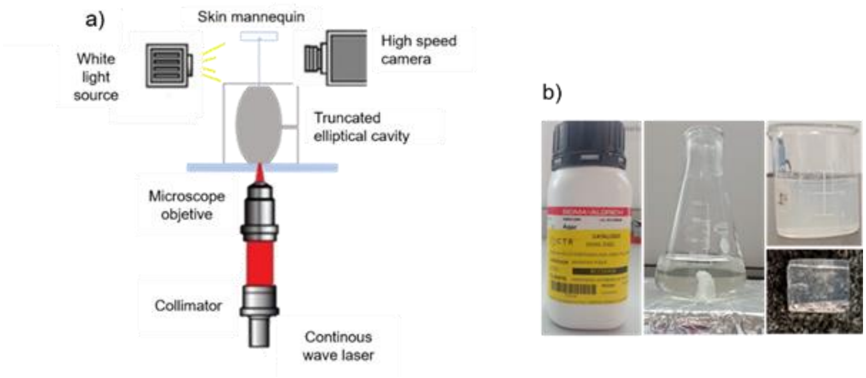

Fig. 1. a) Experimental setup. b) Images of the steps to obtain the agar gel.

without the use of a conventional needle. In recent years, high speed liquid jet injection has been studied through optical methods, using pulsed lasers (optical cavitation) [2] and continuous wave lasers (thermocavitation) [3, 4].

Thermocavitation is defined as the process of formation, growth and collapse of a vapor bubble within a highly absorbent solution [3]. The generation and expulsion of liquid jets from the phenomenon of thermocavitation is usually carried out due to the expansion and collapse of a thermocavitation bubble [5]. In this work a new optimized device was designed (SolidWorks), built (3D printer) and validated for the injection of liquid jets into agar gels, usually used as skin phantoms due to their biomechanical properties like human skin.

2 Experimental Setup

A beam from a continuous wave laser (λ=980 nm) is focused down with a microscope objective with optical distance of 8 mm (beam waist of 480 µm at focus) into an elliptical cavity filled with a saturated solution of copper nitrate (13.78 g of $Cu(NO_3)_2$ per 10 ml of water). The absorption coefficient of the solution is α=135 cm^{-1} In order to record the formation and evolution of an individual bubble, the was illuminated using a white light source to project the bubble´s shadow on a high-speed video camera (Phantom VEO 710L), which was used to capture 35,000 images in one second at a resolution of 320 x 504 pixels (See Fig. 1a).

Skin phantoms were placed 5 mm from the device's ejection channel. All the videos obtained were analyzed in the "Phantom Camara Control Application" software. For the preparation of the skin phantoms, agar gel (Sigma Aldrich,) was used at a concentration of 1.0%. That is, 1 g of agar powder is dissolved in 100 ml of water. After solidification, pieces of agar were obtained with an approximate size of 3 cm long by 3 cm wide and 0.5 cm thick, as observed in Fig. 1b.

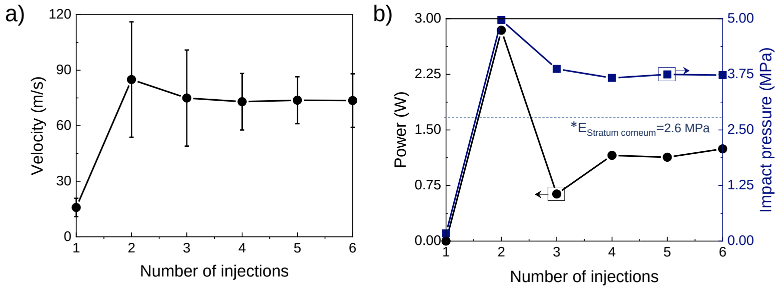

Fig. 2. a) Average speed, b) Power and impact pressure of the 6 ejected jets.

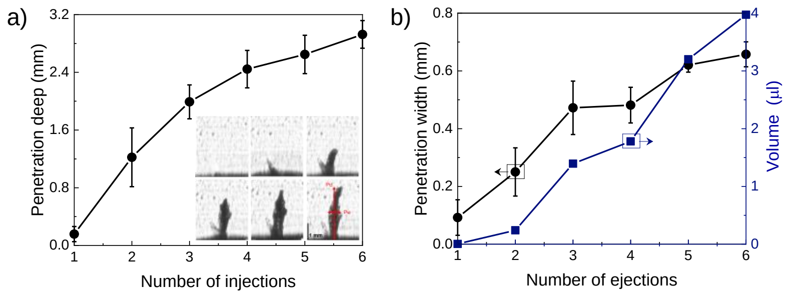

Fig.3. a) Penetration depth, b) Penetration width and volume delivered by the 6 liquid jets.

3 Results

In this work, penetration tests were carried out under the same experimental conditions in triplicate. Initially, the solution is irradiated at a power of 400 mW for a time of approximately 1s. With the help of the fast camera, it was possible to study the dynamics of the first 6 ejected liquid jets, as shown in Fig. 2. Maximum velocity (~85 m/s), power (~2.84 W) and impact pressure (~ 4.97 MPa) are presented in the second ejected jet.

In Fig. 2b shows the impact pressure of the ejected liquid jet when it hits the surface of the gel, value that indicates if the liquid jet has sufficient capacity to penetrate the different layers of the skin. According to the literature, it has been reported that the pressure required to break the stratum corneum is ~2.6 MPa, while only a value of ~1.1 MPa is required to break the epidermis [6].

In Fig. 3a it is shown the penetration depth reached after each ejected liquid jets, reaching the depth of ∼2.9 mm at the sixth shot. Fig. 3b shows the value of the estimates of the penetration width and the volume of liquid injected by the device (approximately ~ 4 µl), as a function of the number of shots.

Fig. 4a shows the evolution of penetration of the 6 liquid jets inside the skin phantom at a concentration of 1.0%. The liquid injected into the sample occurs until the second shot (Fig. 4b), hence the penetration depth is progressive as the number of shots increases, until reaching a maximum penetration distance (see Fig. 4f).

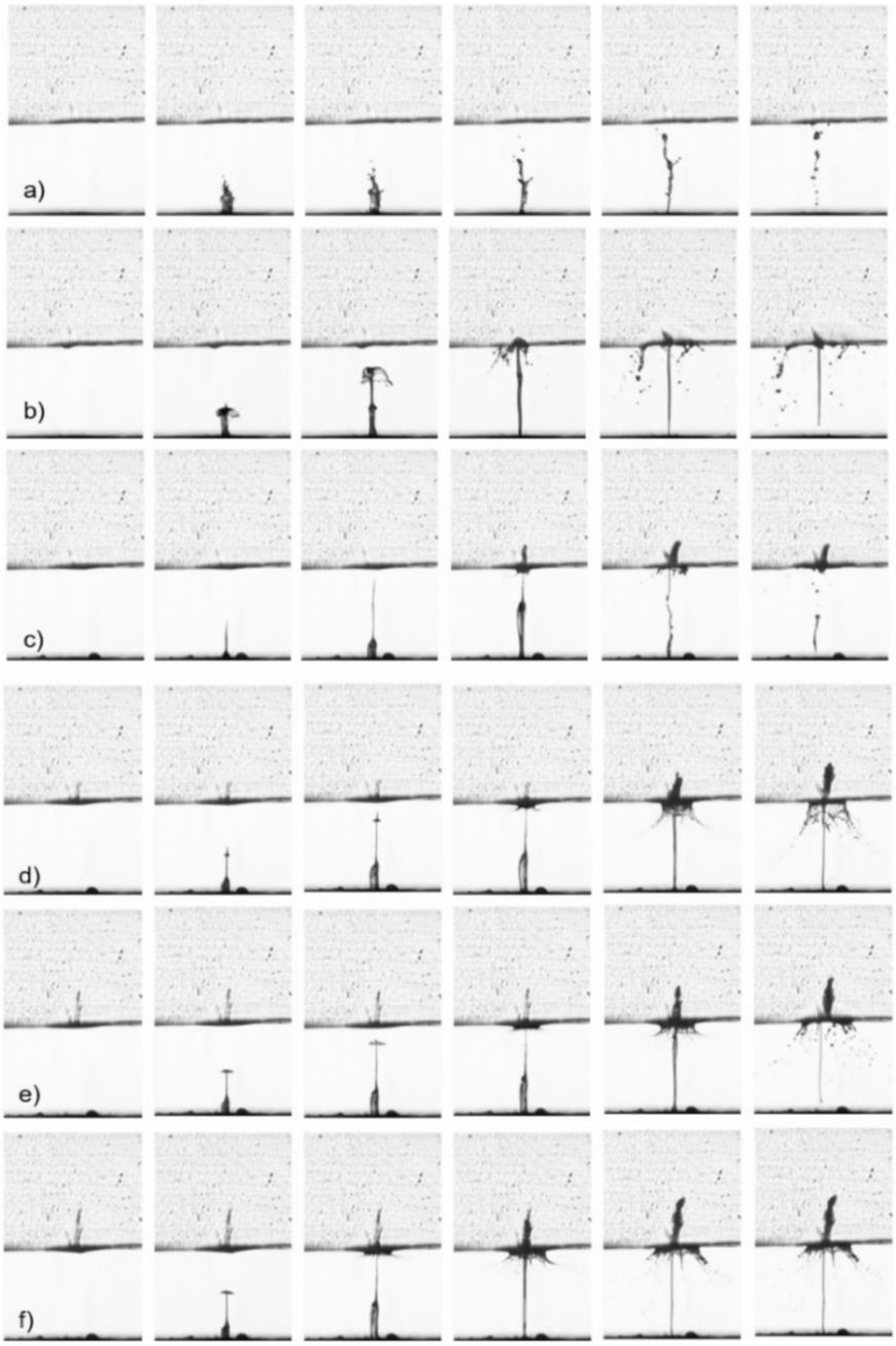

Fig. 4. Evolution of the penetration dynamics of liquid jets in agar gel at 1.0%. a) first shot, b) second, c) third, d) fourth, e) fifth and f) sixth shot.

4 Conclusions

A microfluidic device was developed with the ability to eject liquid jets at high speeds that can reach and exceed 85 m/s, caused by the high concentration of the kinematic energy of an acoustic wave emitted after the collapse of the thermocavitation bubble. The liquid jets generated can penetrate skin phantoms made from agar gel at a concentration of 1.0%, achieving a penetration distance of ∼2.9 mm and a delivered volume of ~ 4 µl at the sixth shot. It is also reported that the maximum power (2.84 W) and impact pressure (4.97 MPa), a value that allows us to compare the efficacy of the microfluidic device with those already reported in the literature, this being a good option for the administration of drugs free of needles.

References

1. Mitragotri, S.: Current status and future prospects of needle-free liquid jet injectors. Nature Reviews Drug Discovery, vol. 5, no. 7, pp. 543–548 (2006) doi: 10.1038/nrd2076
2. Han, T. H., Yoh, J. J.: A laser based reusable microjet injector for transdermal drug delivery. Journal of Applied Physics, vol. 107, no. 10, pp. 1–4 (2010) doi: 10.1063/1.3430989
3. Padilla-Martinez, J. P., Berrospe-Rodriguez, C., Aguilar, G., Ramirez-San-Juan, J. C., Ramos-Garcia, R.: Optic cavitation with CW lasers: A review. Physics of Fluids, vol. 26, no. 12, pp. 16–20 (2014) doi: 10.1063/1.4904718
4. Cu, K., Bansal, R., Mitragotri, S., Fernandez-Rivas, D.: Delivery strategies for skin: comparison of nanoliter jets, needles and topical solutions. Annals of Biomedical Engineering, vol. 48, no. 7, pp. 2028–2039 (2020) doi: 10.1007/s10439-019-02383-1
5. Zaca-Morán, R., Castillo-Mixcóatl, J., Sierra-González, N. E., Pérez-Corte, J. M., Zaca-Morán, P., Ramírez-San-Juan, J. C., Ramos-García, R., Padilla-Martínez, J. P.: Theoretical and experimental study of acoustic waves generated by thermocavitation and its application in the generation of liquid jets. Optics Express, vol. 28, no. 4, pp. 4928–4937 (2020) doi: 10.1364/OE.375900
6. Geerligs, M., van Breemen, L., Peters, G., Ackermans, P., Baaijens, F., Oomens, C.: In vitro indentation to determine the mechanical properties of epidermis. Journal of Biomechanics, vol. 44, no. 6, pp. 1176–1181 (2011) doi: 10.1016/j.jbiomech.2011.01.015