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Design and Experimental Evaluation of Mosquito-Inspired Surgical Needle

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ABSTRACT

Insects steer their stingers effortlessly to a specific target and release their venom in a certain path through the skin with minimal pain. These unique traits inspire the idea to develop bioinspired needles to reduce the insertion forces and to decrease the needle path deviation (deflection) for improved targeting accuracy. Our approach in this work focus on the design of mosquito-inspired needle and the evaluation of the needle performance using vibration during tissue insertion. The mosquito-inspired needle design specifically consists of maxilla-shaped and labrum-tip design. The insertion force was measured using a force sensor, which was fixed at the needle end to measure the uniaxial force of needles. The applied vibration on the needle was measured along linear axis using piezoelectric actuator with a frequency of 150 Hz and an amplitude of 5µm. The needle was inserted at a constant speed by attaching the needle to a motorized linear stage. It was observed that the insertion forces of the proposed needle design with vibration showed a reduction of insertion force by 27% compared to that of a conventional needle. This reduction in insertion force means that there is decrease in tissue gel phantom damage and it was also observed that needle bending has reduced due to reduction in bending stiffness of the tissue phantom. Furthermore, the needle insertion tests in real tissues (bovine kidney) considering the proposed needle geometry and vibration will be studied in future work to understand the bioinspired needle-tissue interactions.

INTRODUCTION

Needles are commonly used in medical procedures to reach the target locations inside of the body to treat various cancer interventions. These include both diagnosis and therapy such as in vivo analysis using optical, raman spectroscopy, chemicals, as well as brachytherapy, photodynamic therapy, rf-based thermal ablation, biopsy, and viral/gene therapy. Another common needle procedure is biopsy. For example, a core needle biopsy technique is commonly used to extract tissue samples. A sample of tissue is cut and taken from the organ with a needle using an ultrasound guided percutaneous approach and is then assessed for the presence of cancerous cells by histopathological analysis or molecular profiling. Needle steering inside a tissue is dictated by the mechanical interaction of the needle with tissues. The effectiveness of needle insertion in these procedures is highly dependent on insertion target accuracy, which is influenced by various factors including the properties of tissue, needle geometry and insertion speed. To minimize the target placement errors, a practical approach is to reduce insertion force. Recently there has been tremendous interest in the medical community to develop innovative surgical needles to reduce insertion force and tissue damage during percutaneous procedures.

Insect stingers of honeybees, wasps, scorpions, and mosquitos have sophisticated sting mechanics and morphological structures. The research efforts to mimic insect stingers have been studied in the past with penetration mechanism such as honeybee [1] and mosquito [2] to help facilitate better needle insertion. Mosquito is known for its exceptional penetration mechanism with minimal painless needle called fascicle. Previous studies have shown that the mosquito proboscis insertion strategy reduces insertion force and decreases tissue damages. One specific aspect of the mechanism is the vibration of the needle during insertion. Due to its penetrating technique in reducing insertion forces with minimal pain [3,4], a mosquito inspired vibration has gained interest among the research community. Therefore, in this work, the mosquito inspired vibration and the needle geometry design was investigated experimentally.

The hypothesis of mosquito's penetration mechanism has been studied by many researchers [5,6]. But the influence of the needle body geometry inspired from the mosquito proboscis (the fascicle) has not been reported. The mosquito proboscis consists of a fascicle, i.e., a labrum tube (a primary path for blood flow), as shown in Figure 1. The maxilla needle is used to cut the tissue and mandibles are used to hold the tissue. as shown in Fig.1(c) the labrum tip for fluid intake and Fig. 1(d) the maxilla shape for cutting the tissue. From these studies, the concept of having the maxilla -shape on the surgical needle with addition of vibration helps to reduce insertion force and minimize the target placement error. In this work, we design the bioinspired needle and evaluate its performance with applied vibration during insertion into tissue.

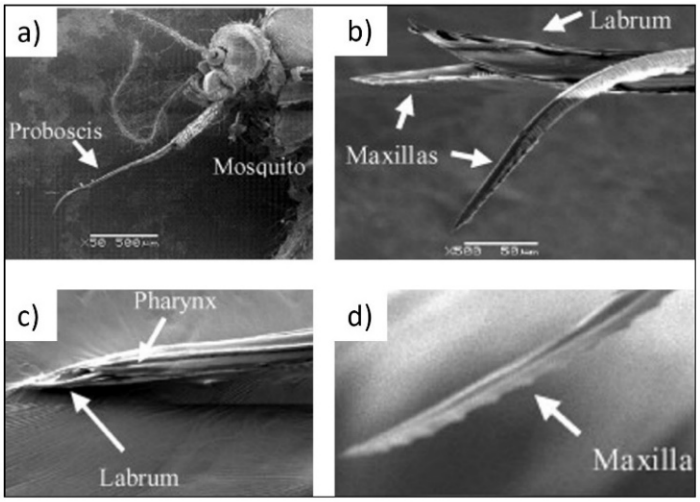

FIGURE 1: Mosquito proboscis SEM images from top left a) the proboscis b) needles involved in proboscis c) labrum tip and d) maxilla shape [5].

MATERIALS AND METHODS

Mosquito-inspired needle in this work consists of labrum tip and modified maxilla shape as shown in Fig. 2. The standard bevel-tip needle and bioinspired needle are designed with the help of SEM images from Izumi *et al* [5]. Solidworks software (Dassault Systèmes SolidWorks Corporation, Waltham, MA) is utilized to modify the mosquito inspired needle. Both of these needles have the same diameter of 1.65 mm (16 gauge), the length of 150 mm, a needle bevel-tip of 45°, and a labrum-tip radius of 12 mm to create the modified shape of the needle. These 3D models are then manufactured using Object Connex 350 3D printer (Stratasys, Inc., Eden Prairie, MN) as shown in fig 2b).

The number of maxilla-shape on the needle were 10 and separated by the thickness of 0.2 mm. The thickness between each maxilla-shape gives the strength that is required for the needle during insertion into soft tissue. The higher thickness would result in higher needle bending because of increase in gap between each maxilla-shape. The length of each maxilla-shape on the needle is 4.5 mm and with thickness between each maxilla-shape structure is 0.2 mm can reduce the needle to bend during insertion.

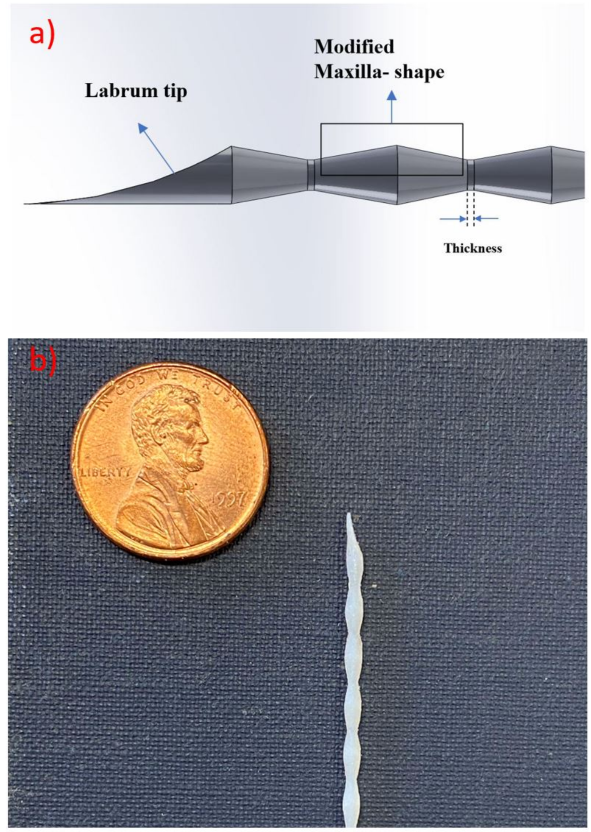

FIGURE 2: a) CAD model showing 16-gauge bioinspired needle with labrum-tip, modified maxilla shape and thickness (t) = 0.2mm and b) 3D-printed bioinspired needle prototype.

The needle insertion test setup shown in Fig. 3 consists of a motorized linear stage (Velmex Inc., Bloomfield, NY, USA) and a piezo actuator (Physik Instrumente, Auburn, MA) to vibrate the needle. A force sensor, a six-axis F/T Transducer Nano17® (ATI Industrial Automation, Apex, NV) is used to record the insertion force with vibration effect. The needles are inserted into the PVC gel phantom at a constant velocity of 1 mm/sec by attaching the needle to a linear stage as shown in Fig. 3. The force sensor is fixed and piezo is attached to the needle to vibrate at a frequency of 150 Hz and an amplitude of 5µm.

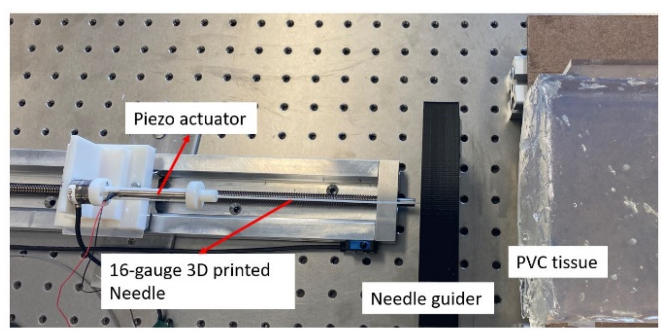

FIGURE 3: Needle insertion test setup (top view)

The insertion tests into PVC gel phantom made of plastic softener and polyvinylchloride suspension (M-F Manufacturing Co., Ft. Worth, TX) are performed using the 3D printed needles. The viscoelastic properties of the gel phantom are fabricated to mimic the elastic properties of the soft tissue.

RESULTS AND DISCUSSION

The insertion forces of mosquito-inspired and standard bevel-tip needles are measured as it travels in the PVC gel phantom. As the needle impacts the soft tissue the resulting force is measured on the force transducer. The force increases with needle displacement until the tissue is penetrated and the force change is seen with two different needles i.e. bioinspired and standard bevel-tip needle. The force increases with the standard bevel-tip needle compared to bioinspired needle. This is due to the design geometry on the needle inspired from mosquito labrum-tip and maxilla-shape. The maximum insertion force shown in Fig. 4 is regarded as the force required for tissue penetration.

As seen in Fig. 4, there is a significant decrease in insertion force by 27% using mosquito-inspired needle. The vibratory motion during needle insertion lowers the insertion force. The insertion force is reduced from -1.61 N to -1.17(a reduction of about 27%). The experiments confirm that the novel design and the vibration technique can be applied and the effect of the two strategies can help in reducing insertion force specifically when dealing with soft tissues.

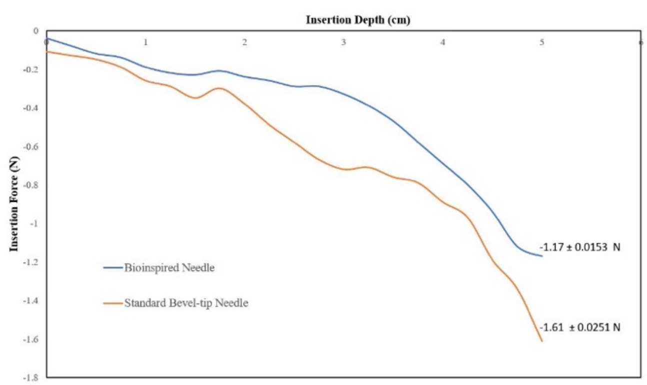

FIGURE 4: Insertion force versus insertion depth for bioinspired needle and standard bevel-tip needle.

The decrease in insertion force is due to decrease in frictional force. The decrease in frictional force is due to the contact area reduction in the needle with maxilla-shape and applied vibration. Also, it is shown that the puncture force also decreased because of the labrum-tip compared to bevel-tip on the needle. Both the strategies demonstrated in this work namely, labrum-tip and maxilla-shape along with applied vibration had a noticeable effect to reduce the insertion force. Also, it is conjectured that the extraction forces will be reduced due to the applied vibration on both needles. But the reduction in extraction forces is more likely to occur using mosquito-inspired needle due to reduced contact area with vibration. The application of vibratory actuation during bioinspired needle insertion reduces the amount of force required for needle penetration.

Additionally, the interaction between needle and gel/tissue is ongoing to understand the insertion mechanics with FEA simulation and to optimize the needle geometry. Also, different parameters such as insertion velocity, needle geometry and applied vibration will be important in understanding the interaction between tissue and gel with mosquito-inspired needle.

CONCLUSION

It has been demonstrated that geometrical shape modification such as labrum-tip (needle-tip) and modified maxilla shape inspired by mosquito proboscis could be utilized to significantly decrease the insertion force (Fig. 4). The insertion force reduced by 27% with dynamic bioinspired needle insertion compared to standard bevel-tip needle insertion. Furthermore, the needle insertion tests into real tissues such as bovine brain will be studied in the future work to understand the bioinspired needle-tissue interactions.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Sahlabadi M and Hutapea P, "Novel design of honeybee-inspired needles for percutaneous procedure," *Bioinspiration and Biomimetics,* 13, 036013, 2018.

[2] Ramasubramanian M K, Barham O M and Swaminathan V, "Mechanics of a mosquito bite with applications to microneedle design," *Bioinspiration and Biomimetics,* 3, 046001, 2008.

[3] Lenau T A, Hesselberg T, Drakidis A, Silva P and Gomes S, "Mosquito inspired medical needles," *Bioinspiration, Biomimetics, Bioreplication,* 10162 1016208, 2017.

[4] Aoyagi S, Izumi H and Fukuda M, "Biodegradable polymer needle with various tip angles and consideration on insertion mechanism of mosquito's proboscis," *Sensors Actuators A: Physical.* 143 20–8, 2008.

[5] Izumi H, Suzuki M, Aoyagi S and Kanzaki T, "Realistic imitation of mosquito ' s proboscis : Electrochemically etched sharp and jagged needles and their cooperative inserting motion," *Sensors Actuators A: Physical,* 165 115–23, 2011.

[6] Gidde STR, Ciuciu A, Devaravar N, Doracio R, Kianzad K and Hutapea P, "Effect of Vibration on Insertion Force and Deflection of Bioinspired Needle in Tissues", *Bioinspiration and Biomimetics,* 2020 (accepted and pending).