Insertion Mechanics of Curved Bio-inspired Needles

Doyoung Kim and Parsaoran Hutapea

Department of Mechanical Engineering, College of Engineering, Temple University

Composites Laboratory

TEMPLE UNIVERSITY
College of Engineering

Introduction

- Needle insertion is an essential process during minimally invasive surgery (MIS), which has been used for biopsies, blood sampling, and brachytherapy.
- The minimally invasive procedure involves less intrusive and fewer post operations than traditional open surgeries, so this leads to fast recovery times, and decreased risk infection.
- For successful diagnosis and treatment, accuracy of needle insertion is vital, and previous studies are shown that insertion force, tissue deformation, and tissue damage can affect needle insertion precision.
- Insertion force, which is composed of stiffness, cutting, and friction force can be affected by the geometry and materials of the needle, mechanical properties of tissue, and insertion velocity.

Motivation & Objective

- The traditional biopsy needles can cause harm to the patient, including tissue damage, bleeding, and pain.
- An essential aspect of the study is the mechanics and geometry of the needle, which plays a crucial role in its performance.
- This study focuses on decreasing insertion force, which is the total applied force of the needle that is coming from the tissue or organ.
- The study incorporates structures such as curved insect's stinger to achieve a balance between penetration and minimal insertion force.

Materials and Methods

- Bevel and curved tip needles are 3D printed with Vero Ultra material, which has young's modulus of 2.0-3.0GPa (Figure 1) : length of 150mm and diameter of 3mm.
- Needle insertion force measurement experiment setup with linear actuator, force sensor, and phantom tissue (Figure 2).
- Phantom tissue is created using polyvinyl chloride (PVC) tissue-mimicking material: the PVC polymer and a softener.
- Needles are tested for insertion and extraction force measurement: insertion velocity of 1mm/s and depth of 10cm.

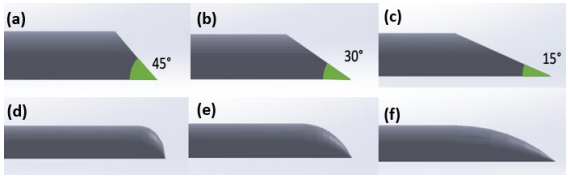

Figure 1 Different Tip Geometry: Bevel Tip with different angles (a-c), and curved tip (d-f)

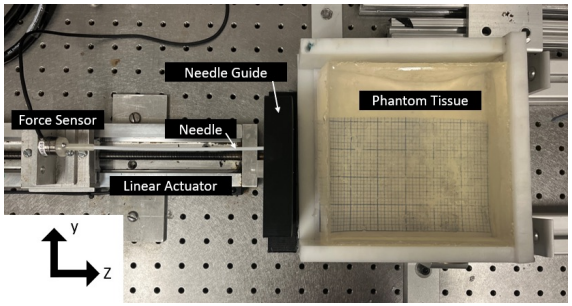

Figure 2 Experimental Setup for measuring needle insertion and extraction forces

Results

- Since forces in x and y direction are relatively smaller than force in z direction, forces are in those direction are negligible. (Figure 3-(a))
- Maximum insertion and extraction force values are shown in Table 1.
- The maximum insertion forces of bevel tip needles of 45, 30, and 15 degrees are 2.83N, 2.20N, and 3.08N respectively.
- The maximum insertion forces of bevel tip needles of 45, 30, and 15 degrees are 3.59N, 1.97N, and 2.39N respectively.
- Insertion force is reduced for 30 degrees and 15 degrees curved needle, but 45 degrees curved tip needle does not reduce insertion and extraction forces. (Figure 3-(b), (c), and (d))

Table 1 Maximum insertion and extraction forces value of bevel and curved tip needles and reduction in percentage

Forces	45 degrees		30 degrees			15 degrees		
	Bevel	Curved	Bevel	Curved	Reduction	Bevel	Curved	Reduction
Insertion (N)	2.83	3.59	2.20	1.97	10.5 %	3.08	2.39	22.4 %
Extraction (N)	1.91	2.11	1.87	1.48	20.8 %	2.02	2.42	N/A

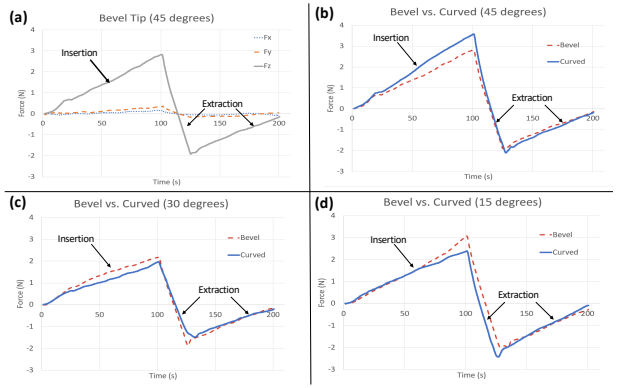

Figure 3 (a): Insertion and extraction forces in x, y, and z direction of 45 degrees bevel tip needle. Insertion and extraction forces in z direction of bevel and curved tips of 45 degrees (b), 30 degrees (c), and 15 degrees (d).

Conclusion & Future Work

- 30 degree curved tip needle reduced insertion and extraction forces by 10.5% and 20.8% respectively.
- 15 degree curved tip needle reduced insertion force by 22.4%.
- Based on this preliminary study, some of curved tip design has a potential to reduce insertion and extraction forces.
- Tissue damage will be studied in the future to conclude reducing insertion and extraction force helps lowering the damage of the tissue.
- Bio-inspired curved needle will be further developed for reducing forces and tissue damage, and increasing target accuracy.

References

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