

# Blood-mimicking delivery in polygonal structure of inner quadrupletip microneedle with valveless micro-pump

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**Abstract.** This paper presents a titanium quadrupletip micro-needle integrated with a micro-pump with different inner designs, length and diameter of the micro-channels to measure and maximize the velocity flow in the micro-needle as blood delivered into human body. Titanium is used as the material of the micro-needle which are also the common material in manufacturing of micro-needle. The advancement of micro-needle technologies is improved in penetrating human outermost skin, stratum corneum and further to human blood vessels. The micro-needles with channel inner design of circular, square, hexagon, and dodecagon with quadruple tip designs are drawn with inner diameter parameter of 150 $\mu$ m and 100 $\mu$ m with two different channel length which are 10mm and 25mm. The characteristics of blood delivery in geometrically changed inner designs affect the output velocity in microneedle when the micropump is operating. The results showed that, when it is pumped at 0.04m/s, the blood velocity improved by 5.6% than when the pump is increased by 30% of its capacity. This is due to the backflow generated in the micropump.

## 1. Introduction

Delivering or withdrawing blood techniques are obtained either from arteries or veins mostly by using hypodermic needle to penetrate human skin. For hypodermic needle to reach the arteries or veins are surely uncomfortable and painful. The realization of painless needle from mosquito's mechanism of blood withdrawal, lots of research are done to improve the efficiency of the micro-needles for blood delivery from various sizes of needle and designs. Needles are defined as sharp hypodermic needle that has a function to be painless while completing the task of penetrating the human outermost skin to withdraw blood or injecting fluid into the blood stream [1]~[4]. The advancement of the research leads to the technologies of micro-needles in improving the flow and performance which includes attaching micropump at the microneedle [5]. While keeping microneedle in a longer length, the design parameters



of the microchannels differ in order to obtain higher velocity. This is a requirement whenever the control of the intravenous infusion of blood is necessary.

### *1.1 Micro-needle developments*

An early development of microneedles are aimed for the diabetes patients that needs to take insulin regularly. The efforts to bypass the stratum corneum are aimed at altering the medication molecule to make it more lipid soluble which will enhance drug penetration. Micro-needles are inserted at a depth of 1mm within the skin yielded rapid insulin absorption and an adequate reduction of glucose level. Small bore micro-needles can deliver insulin, a relatively small molecule, through the skin in amounts adequate for managing the patient's glucose levels and bypass the stratum corneum easily.

### *1.2 Expansions of micropump*

In recent years, micro-pump has become available for industrial product integration in microfluidic research which is one of special interest of MEMS technology. Micro-pumps were started in middle 1970s. Before 1990s, mechanical pumps were mainly studied. After 1990s, non-mechanical pumps were introduced. In 1975, Thomas and Bessman were presented a documents about designing a micro-pump for implantation for human body. It contain multi piezoelectric disc benders combine with solenoid valve and pumping chamber. In 1984, Smits was patented the silicon micro fabrication technologies and later he published the peristaltic pump which is consists of three piezoelectric discs in 1990. The purpose of the micro-pump was for his insulin delivery systems [6]. Micropumps can be classified into two categories, either mechanical or non-mechanical micropump [7].

### *1.3 Piezoelectric micropump*

In biomedical application, a typical micropump such as MEMS device, the actuation source is placed through a fluid sample (drugs and therapeutic agents) where the fluid is being transferred. A mechanical micro-pump such as piezoelectric micro-pump is widely used in biomedical field. The conversion of mechanical energy to electronic signal (voltage) and vice versa is called piezoelectric effect. A stress applied to such materials will alter the separation between the positive and the negative charges, causing surface net polarization. The piezoelectric effect relates to the coupling between mechanical deformation and electrical polarization. Main advantages of piezoelectric actuators include large actuation force, fast response and simple structure. Their fabrication, however, is complex as is processing of piezoelectric materials [8].

## **2. Methodology**

The analysis of the velocity flow used in the simulation will be using Ansys Fluent software. The micro-needle attached to a micro-pump will be drawn first in 3 dimensional drawing. The actual laminar inflow of fluid will be inserted as the inlet velocity of the micro-needle in order to simulate the velocity flow in the micro-needle. The purpose of this simulation is to show the velocity profile of the blood during delivery in the micro-needle with the direction of the fluid flow.

### *2.1. Blood as a non-newtonian fluid*

Blood is a heterogeneous multi-phase mixture of solid corpuscle contains of red blood cells, white blood cells and platelets [9]. Characteristics of blood are determined by the properties of these components and their interaction with each. Based on properties of blood, 0.004 Pa\*s dynamic viscosity and 1060 kg/m<sup>3</sup> density is used in the simulation. External physical condition of the blood rheology is neglected. Although in most cases the effect is not substantial except possibly over short periods of time and normally does not have lasting consequences.

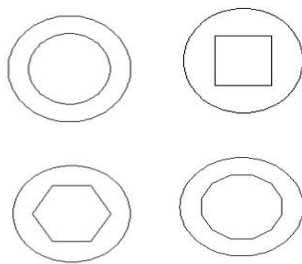
## 2.2. Design of micropump

The design and drawing of micro-pump is based on one company that sell micro-pump which is suitable for blood delivery. For blood delivery, it requires a micro-pump that handles a high viscosity liquids to pass by the actuator in the micro-pump. The important things in choosing micro-pump is it has to be suitable and has the compatibility in biomedical industry. The dimension of the micropump is 55x35x35 mm. The inner part of the micropump is shown in figure 3.

## 2.3 Design of micro-needles

For the flow improvement research, the micro-needles with channel inner design of circular, square, hexagon and dodecagon are designed with the parameter of 100 $\mu$ m inner-diameter and 150 $\mu$ m inner-diameter with three different channel length 10mm and 25mm. The figure 1 shows the designated micro-needles that involved in this research.

Micro-needles for tip designs are made up of Titanium 6Al4V, hollow cylinder are previously simulated as they are almost penetrating the rubber, which acts as the outermost layer of human skin [10]. Figure 2 shows the designated tip of the micro-needles that is being used in this research which is quadrupletip micro-needle. The authors previously designed and changed geometries of machineries showed improvements in obtaining better dynamic characteristics [11]~[12].



**Figure 1.** Inner design of micro-needle.



**Figure 2.** Quadrupletip micro-needle.

## 2.4 ANSYS Fluent

This research is focused more on the fluid flow velocity in micro-needles respect to the various design, length and diameter of micro-needles during blood delivery. Different translational speed of micropump's diaphragm is applied in the simulation but the properties and inlet velocity remains the same. The translational speed of the diaphragm will be 0.04m/s and 0.08m/s respectively. Wall between the diaphragm and the fluid is applied for these translational speed movement.

## 3. Modelling

In ANSYS Fluent, microneedle and micropump have to be meshed inside as the delivery of the fluid is flowing from the inlet of micropump to the end of the micro-needle. The meshing of the model helps to receive an accurate, precise result and minimize error occurs during calculation. The finer the mesh, the more accurate result is obtained.

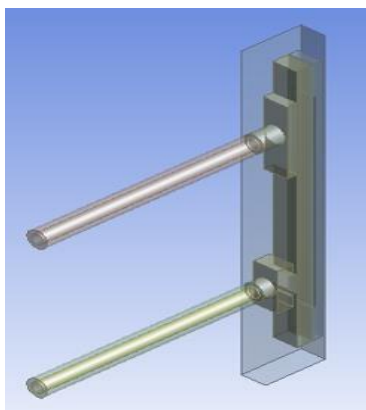
As shown in table 1, meshing for the models are briefly explained in which mesh sizing of the model is used. The meshing for both microneedle and micropump is using fine meshing. Same goes to the fluid flow in the microneedle and micropump, the meshing is set to fine. Table 2 shows the details of number of nodes and number of elements for the whole simulation domain. Figure 4 and 5 below show the meshed model of micropump and microneedle.

**Table 1.** Meshing size.

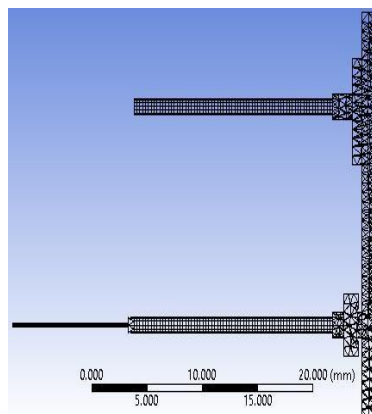
Type	Details
Relevance center	Fine
Smoothing	Medium
Span angle center	Coarse
Minimum edge length	$8.6926 \times 10^{-2}$ mm

**Table 2.** Simulation meshed domain.

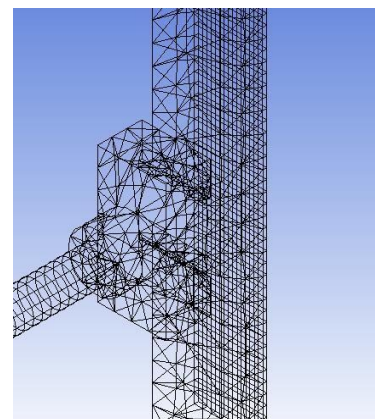
Parts			No. of nodes	No. of elements
Micro-pump			57832	13956
Micro-needle	Diameter, $\varnothing$ (mm)	Length (mm)		
<b>Circular</b>	0.10	10	19253	5950
	0.15	10	9551	5567
	0.10	25	12372	7849
	0.15	25	10543	6575
<b>Square</b>	0.10	10	10094	3514
	0.15	10	8339	4526
	0.10	25	7786	4449
	0.15	25	7899	4518
<b>Hexagon</b>	0.10	10	16859	5335
	0.15	10	8382	4909
	0.10	25	10917	6807
	0.15	25	8091	4867
<b>Dodecagon</b>	0.10	10	22245	11722
	0.15	10	18049	11132
	0.10	25	20331	13650
	0.15	25	19310	12702



**Figure 3.** Micro-pump model.



**Figure 4.** Full model mesh.



**Figure 5.** Cross-sectional view of meshed micro-pump

## 4. Results and discussions

The flow simulation of blood delivery in the micro-needle is done by using ANSYS Fluent. The purpose of the simulation is to study the blood flow characteristic during the delivery passing by micropump into the microneedle. Various design parameters of microneedle had been designed and simulated.

### 4.1. Simulation results

**4.1.1. Flow delivery when pumped at 0.04m/s.** The microneedles designed as shown in figure 1 and 2 at previous section are used in this simulation attached to the micropump. The micropump is set at 0.04m/s for the diaphragm's translational movement. The results are then tabulated to show the value of the average velocity result of blood delivery in circular, square, hexagon and dodecagon micro-needle penetrating the human skin. The highest velocity using different inner shape of the micro-needle shows the amount that has the best performance of delivering blood. The results are tabulated to compare with other inner design of micro-needle.

Table 3 shows the comparison of different inner design of microneedles between velocities of blood flow in each inner design with their respective details of diameter and length of the microneedles. Figure 6 shows the graph result of the simulation for the blood flow. It shows that having a dodecagon inner design with 0.1mm diameter and 25mm length has the best design for blood delivery when the micropump is being pumped at 0.04m/s. The velocity of the blood flow is 0.8050m/s.

**4.1.2. Flow delivery when pumped at 0.08m/s.** The microneedles designed as shown at previous section are used in this simulation attached to the micropump. The micropump is set at 0.08m/s for the diaphragm's translational movement. The results are then tabulated to show the value of the average velocity result of blood delivery in circular, square, hexagon and dodecagon micro-needle penetrating the human skin. The highest velocity using different inner shape of the micro-needle shows the amount that has the best performance of delivering blood. The results are tabulated to compare with other inner design of micro-needle.

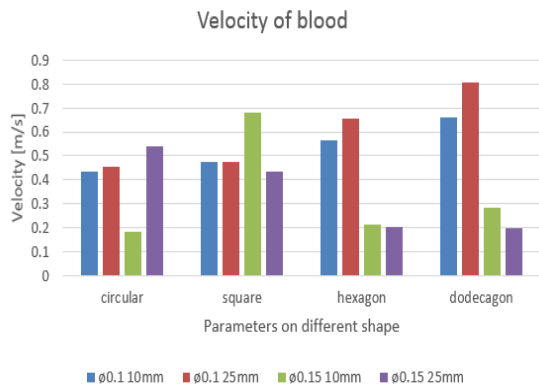
Table 4 shows the comparison of different inner design of microneedles between velocities of blood flow in each inner design with their respective details of diameter and length of the microneedles. Figure 7 shows the graph result of the simulation for the blood flow. It shows that at 0.08m/s of the diaphragm's translational movement, having a dodecagon design with diameter of 0.1mm and 25mm length has the best blood flow performance. The velocity of the blood flow is 0.7596m/s.

**Table 3.** Comparison of flow velocity at 0.04m/s.

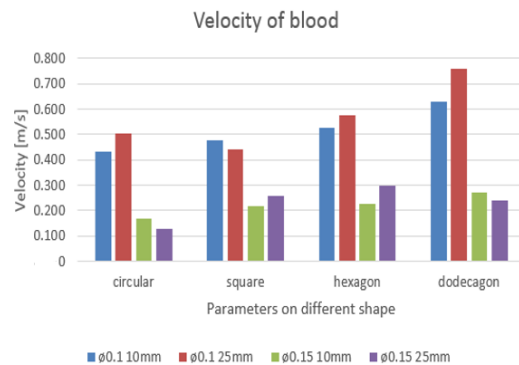
Dia (mm)	Length (mm)	Circle (m/s)	Square (m/s)	Hexagon (m/s)	Dodecagon (m/s)
<b>0.1</b>	10	0.4334	0.4720	0.5676	0.6622
	25	0.4553	0.4758	0.6566	0.8050
<b>0.15</b>	10	0.1815	0.6798	0.2123	0.2804
	25	0.5416	0.4356	0.2026	0.1948

**Table 4.** Comparison of flow velocity at 0.08m/s.

Dia (mm)	Length (mm)	Circle (m/s)	Square (m/s)	Hexagon (m/s)	Dodecagon (m/s)
<b>0.1</b>	10	0.430	0.4759	0.5255	0.6293
	25	0.5012	0.4426	0.5736	0.7596
<b>0.15</b>	10	0.1681	0.2151	0.2233	0.2707
	25	0.1250	0.2590	0.2988	0.2393



**Figure 6.** Blood flow performances at 0.04m/s.



**Figure 7.** Blood flow performances at 0.08m/s.

## 5. Conclusions

In this research, it is numerically proven that, the hydraulic diameter and the length of a micro-needle plays an important role in micro-scale technology. Conclusively, dodecagon inner design of the micro-needle using a 0.15mm diameter and a 25mm length has better performance for blood delivery when it is pumped at 0.04m/s and 0.08m/s. The result obtained shows a slight decreased of average velocity. This is due to the backflow and minor turbulence inside the micropump.

This suggests that a micropump with these settings should have a valve equipped with it to ensure no backflow is present during the blood delivery. As blood is a multiphase fluid flow, it behaves time independently. As time passes, the viscosity decreases while shearing force which are applied affects the velocity in a channel. With a higher external applied force, the slip length increase gradually and causes velocity to increase. Slip length is maximum at small channel widths while it seems to reaches its minimum for greater width. In order to increase the volumetric flow rate of fluid in a microchannel, it is required to have a smaller pressure gradient and by controlling the slip length to be at maximum while the fluid is flowing. With this conditions, a higher velocity is achieved, thus, improving the flow performance and volumetric rate of fluid of a micro-needle.

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