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Investigation of Key Parameters Affecting Microjet Penetration into Skin Tissue in an Air-powered Needle-free Injection System

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1. Introduction

Needle-free jet injection systems (NFJI) are drug delivery devices using a high velocity microjet to penetrate the skin surface and deliver the drugs at a required depth inside the tissue[1–4]. An impulse driven NFJI uses the energy transmitted by a piston to energize the fluid inside the injection chamber and thereby driving it through a micro-nozzle to create a high velocity microjet. The most common mode for energizing the piston is by converting the energy possessed by an expanding gas or air. Such a device are usually termed as an air-powered needle-free injector. The mechanical control of such a system is limited and an effectively designed injection chamber is needed for an effective delivery of drug to the targeted layer. In the present study, we are using experimental and computational studies to identify the effect of various geometrical parameters in the microjet propulsion characteristics.

2. Methods

The peak stagnation pressure of the impinging microjet could be considered a quantifiable parameter for the comparison between the effects of various geometrical parameter. Experimental and computational tools were employed to evaluate the key parametric effects. A commercially available air-powered needle-free injector was selected for the study (Airjet, Union Medical Corp.). The penetration and dispersion characteristics of the microjet was studied by conducting visualization studies in a polyacrylamide (15% concentration) and air medium. The stagnation pressure profile of the impinging jet on the skin surface was found with the help of a force transducer (FSG15N1A, Honeywell) connected with a digital oscilloscope (DSO1014A, Agilent Technologies) having a 25-kHz data acquisition rate.

The computational model was made using a commercially available CFD code (FLUENT 18.1, ANSYS). The dynamic mesh technique was used for giving the transient piston dynamics for this particular problem. The forces acting on the piston was solved using the SDOF solver in the fluent. The forces acting on the piston were given as the input parameter as a UDF. Fig. 1 shows the forces acting on the piston.

3. Results and Discussion

Visualization studies helped in obtaining a better understanding of the dispersion characteristics of microjet in soft materials. It was seen that the incoming fluid of jet penetrates the skin surface after attaining a sufficient energy. It penetrated up to a certain depth inside the soft gel and after which it began the formation

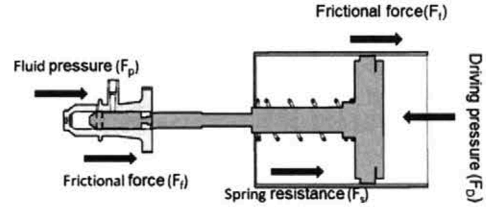

Fig. 1 Schematic layout of the forces acting on the piston.

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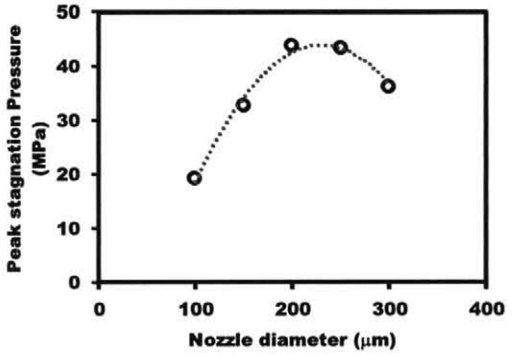

Fig. 2. CFD result on variation of peak stagnation pressure with nozzle diameter.

of a reservoir along with planar cracks. The residual stress inside the reservoir caused the fluid to move out from it after the injection. It was also found that the initial penetration depth depended on the peak stagnation pressure.

The validated computational model was used to predict the effect of various parameters. Obtained results showed that there is an optimum nozzle geometry were the peak stagnation pressure was maximum (Fig. 2). An increase in chamber diameter showed a decrease in peak stagnation pressure for all the filling levels except for a filling level of 0.3 v/V. Nozzle length variation proved to have low impact on the peak stagnation pressure characteristics, while the stand-off distance had an exponential relation with peak stagnation pressure profile. An increase in the angle of entry also showed an increase in the peak stagnation pressure.

4. Conclusion

The experimental and computational studies carried out aided in identifying the key parameters of an air-powered needle-free injection system. Visualization studies done in polyacrylamide medium helped in deriving an understanding of the dispersion characteristics of a microjet inside a soft material.

The validated CFD model developed for modeling the characteristics of the high speed microjet provided useful insight in determining the microjet characteristics at the skin surface. The initial injection depth depends upon the peak stagnation pressure during the initial phase of injection and the parametric effects of various geometrical parameters were explored.

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