A Multiphysics Model for Microparticle Transport through Hypodermic Needles

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INTRODUCTION: Microencapsulation based drug delivery has led to dramatic advances in therapeutic efficacy by providing a controlled release kinetics. However, delivery of microparticles, especially highly concentrated particle solutions through conventional medical syringes can be challenging as particles could get entrapped in the syringe or the needle.

Figure 1. An example of unsuccessful transfer of microparticles (white) during injection with a hypodermic needle

COMPUTATIONAL METHODS: We used Navier-Stokes equation in conjunction with continuity equation in CFD module in COMSOL Multiphysics® V 5.3 to model the velocity field and pressure distribution in a syringe as follows:

$$\rho \frac{\partial \bar{u}}{\partial t} = -\bar{\nabla} p + \mu \bar{\nabla}^2 u + \rho \bar{g}$$

$$\rho \cdot \nabla \bar{u} = 0$$

We then coupled the resulting velocity field to model transport of microparticles in the syringe-needle using Particle Tracing module based on an interplay between drag and gravity forces. The following equation indicates total forces acting on a microparticle:

$$\frac{d(m_p \bar{v})}{dt} = \bar{F}_D + \bar{F}_G + \bar{F}_{Ext}$$

No external forces $(\overline{F_{Ext}})$ was considered in these simulations. A parametric model was constructed as shown in Figure 1. Effect of various parameters on the number of particles (microspheres with a 10 µm diameter) transferred successfully to the needle outlet was then explored.

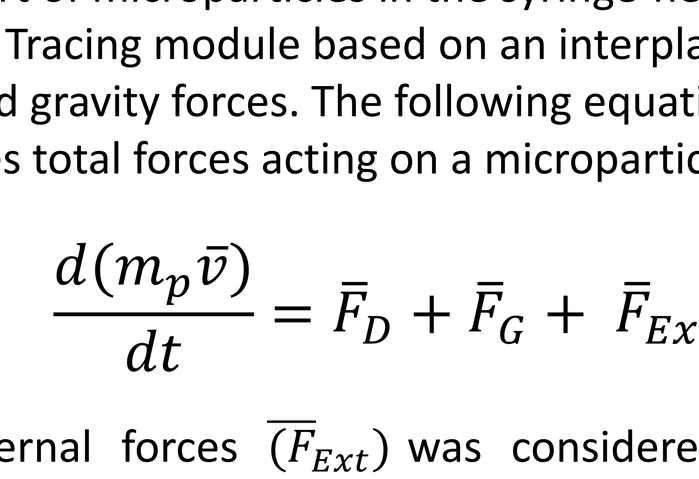

Figure 2. Parametric model used in this study

RESULTS: Figures 3 & 4 represent some examples of the results showing effect of syringe and needle diameter on particle delivery to needle outlet. Based on Figure 4, particles accumulated mostly in the stagnation area close to the diverging streamlines with high pressure and low velocity magnitude.

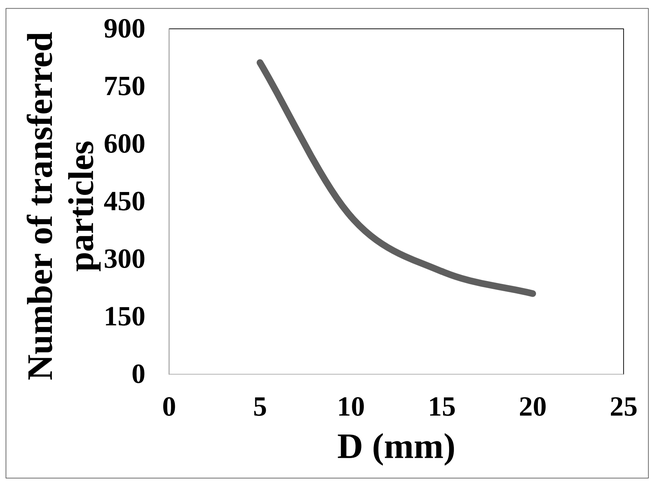

Figure 3. Effect of syringe diameter on successfully delivered particles

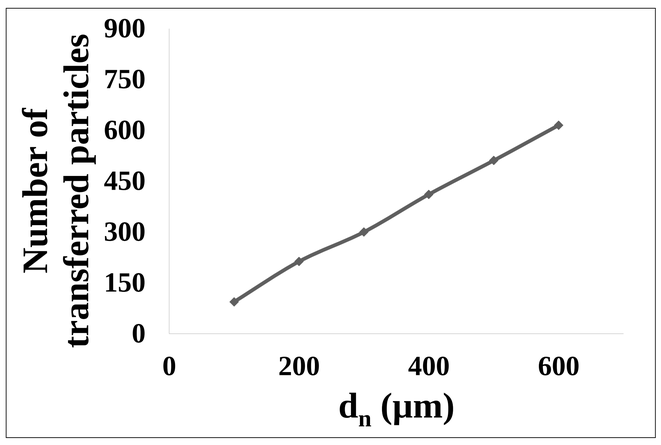

Figure 4. Effect of needle diameter on successfully delivered particles

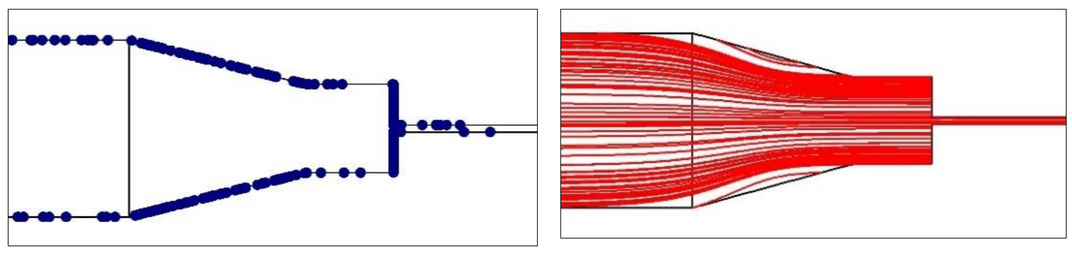

Figure 5. Accumulation location of particles at the end of simulations (left), and corresponding streamlines (right)

CONCLUSIONS: Simulation results highlighted a certain number of design factors as the major design components. It was also concluded that geometry of conventional medical syringes attached to a hypodermic needle would not be optimized for delivery of microparticles. This study highlight the need for design of tailor-made syringes for delivery of advanced drug delivery systems based on microparticles.

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