Multi-objective Optimization of Microneedle Design for Transdermal Drug Delivery

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Abstract

Microneedles have been recognized as a potent and novel method of transdermal drug delivery over the last decade. Despite recent advances in nano- and microfabrication techniques, less is known about the structural properties and design optimization of microneedles in a systematic manner. In this study, we utilize parametric sweep feature from COMSOL Multiphysics® software to explore the effect of various geometrical design parameters such as length of the needle, sharpness, and needle diameter on mechanical performance of microneedles. In order to enhance mechanical stability, the effect of addition of a flange-shape base structure was also examined. To this end, maximum tip deflection, and maximum stress in the structure under buckling, bending and axial loading, when inserted into the dermis, were considered as six objective functions accounting for mechanical performance. Total volume of the microneedle was also considered as another objective function representing maximum deliverable drug volume. Subsequently, parametric study as well as sensitivity analysis was performed on nearly 1000 simulations, obtained from COMSOL® parametric sweep method, to shed light on the importance of each design parameter in overall mechanical stability. Using the resulting analysis, a multi-objective optimization method was then utilized to select the best compromising designs optimizing all seven objective functions simultaneously. This parametric engineering optimization approach using COMSOL® simulations could find extensive applications in conceptual and detailed design stages of microneedles. Particularly, for efficient transdermal drug delivery when trade-off considerations, regrading both skin physiology, namely, efficient penetration and minimal pain, also mechanical stability of microneedles, would be crucially imperative.

Figures used in the abstract

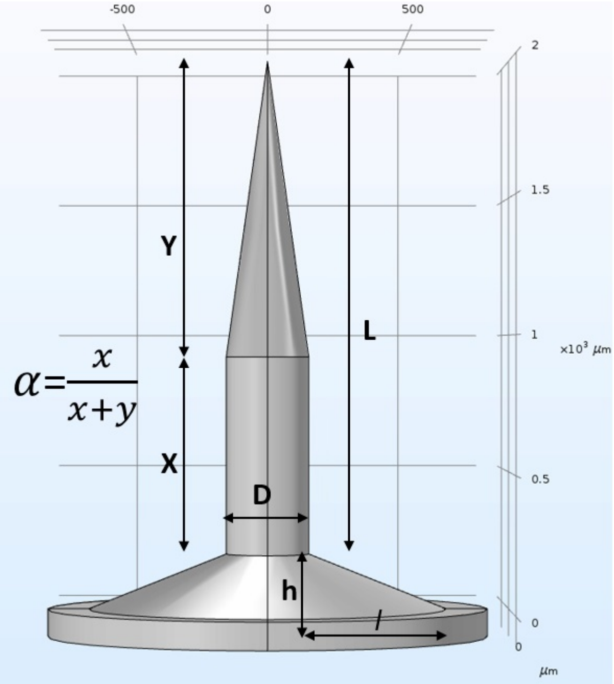

Figure 1: Parametric geometry of a solid microneedle, used in simulations, representing considered design parameters