MEMS BASED STRUCTURAL AND FLUID FLOW MECHANICS AND SIMULATION ANALYSIS OF MICRO NEEDLE FOR DRUG DELIVERY

1NEHA MANE, 2ASHOK GAIKWAD

1Dept. of Instrumentation, All India Shri Shivaji Memorial Society’s Institute of Information Technology, Pune 2Dept. of Instrumentation, Cummins College of Engineering, Pune
Email: neha.mane212@gmail.com, ashok.gaikwad@cumminscollege.in

Abstract— Micro electro-mechanical system (MEMS) is rapidly growing area of interest for a broad spectrum of applications. One particularly fast-growing area is biomedical applications for micromachining technologies. One application of interest to the biomedical industry is the development of micro needles. MEMS (Micro Electro Mechanical System) design systems are used for the development of microneedles, which are used for drug delivery. The drug delivery through microneedle is painless which is not in case of transdermal needles. This paper presents the work in the field of micro needle-based drug delivery with the specific aim of investigating a micro needle-based transdermal patch concept also it presents the characteristics of micro-needles are more reliable. Drug delivery and Fluid extraction requirement in terms of minimal needle dimensions and force withstanding capabilities, which are inversely related to each other. The typical structure of a microneedle is simulated for these studies. The studies show that the typical micro needle with only silicon material can withstand the physical conditions. These studies also show that drugs of various viscosities can be delivered successfully.

Keywords— MEMS, Micro needle, Transdermal patch, COMSOL Multiphysics

I. INTRODUCTION

MEMS is a multiphysics technology that provides many new, innovative ways of implementing devices with functionality. MEMS technology has been inspired by the development of the microelectronic revolution. MEMS is built upon the technological and commercial needs of the latter part of the 20th century, as well as the drive toward miniaturization that had been a driving force for a number of reasons over a much longer period of time. MEMS promise to revolutionize nearly every product category, thereby making the realization of complete system-on-a-chip. MEMS are constructed to achieve a certain engineering function by micro fabrication methods. MEMS technology is progressively being developed for biomedical applications. One application of interest to the biomedical industry is the development of microneedles. The major drawbacks of the conventional needles are pain, risk of infection and the need of trained staff for the injection process. Also, conventional needles are not capable of sampling microscopic volume of fluids, which is often necessary in the world of lab-on-a-chip. The lab-on-chip is the promising new technology that is expected to revolutionize medical diagnostic processes. Using MEMS technology silicon based micro needles are useful for the purpose of insertion of microvolumes of various drugs with minimal invasion of tissue, and thus causing less pain. This paper presents work in the field of Micro system Technology and specifically in the area of micro needle based drug delivery. The objective of this paper is to highlight the potential role of hollow micro needles in achieving painless delivery of drugs across the skin barrier.

II. HUMAN SKIN ANATOMY

The outermost layer of human skin (10-15 Microns) called stratum corneum which is primarily made of dead tissues. The next layer called epidermis (up to 50-100 micron), contains living cells and few nerves, but is devoid of blood vessels. Below the epidermis lies the third layer dermis (300-3000 micron) which contains both nerves and blood vessels.
III. DEVICE DESIGN

Silicon micro needle is proposed for insertion of fluid into the dermis layer. The proposed design is shown in fig. a and fig. b. Also, this micro needle is a cylinder having length 400 µm with internal diameter 200 µm and outer diameter 400 µm. The cylindrical shape of the micro needle body would provide mechanical strength to the needle than any other shape of the needle. Thus it reduces the bending of the needle. The base plane of the needle is considered to be fixed, while the rest of the needle was allowed to move freely. When a micro needle enters the skin it experiences two kinds of forces: a) Buckling force and b) Bending force.

IV. RELATION OF HUMAN SKIN ANATOMY AND MICRO NEEDLE DESIGN CONSIDERATIONS

The microneedle experiences resistive forces by skin when inserted into skin. Therefore, in order to penetrate the microneedle into the skin, the applied axial force on microneedle should be greater than the skin resistive forces. An axial force acts on the microneedle tip during insertion. This axial force is compressive and causes buckling of the microneedle. Failure of microneedle is possible during skin insertion due to bending or buckling. The axial force can be reduced by decreasing the tip area of the microneedle. As buckling is directly related with compressive force, which acts during insertion, sharp microneedle tip reduces buckling. So insertion of microneedle into the skin becomes easy. Hence, the design of microneedle is important for proper delivery without any failure.

V. SIMULATION RESULTS & DISCUSSIONS

A] STRUCTURAL SIMULATION RESULTS OF MICRONEEDLE

For simulation and analysis of micro needle Comsol Multiphysics 4.2a, a software tool is used. To show the effect of this resistive force on the structure of the micro needle, structural analysis was performed using solid mechanics. The maximum stress occurs inside the lumen section of the microneedle, which is well below the yield stress limit with negligible deflection. The result shows that the microneedle design is strong enough to penetrate into the human skin without failure.

The material for the needle was chosen to be silicon (stress of silicon =7 GPa, Young’s modulus E = 160 GPa, Poisson’s ratio = 0.22). The silicon is an appropriate material for micromachining and MEMS. The base plane of the needle was considered to be fixed.

The resistive force offered by the skin before the skin is punctured is given by

\[ F_{\text{Skin}} = P_{\text{Piercing}} A \]  

Where, Piercing P is pressure required to pierce the epidermis layer of skin, which is \(3.18 \times 10^6\) Pa., A is the cross-sectional area of the needle.

The analysis shows that the microneedle can withstand more than 3.18 Mpa. Since the maximum buckling force was substantially larger than the skin resistance force in the microneedle and it should be able to pierce the skin without breaking. When different stresses are applied then displacement of needle is shown in fig c to f.

C) Stress Analysis (apply 80 Kpa)
Above fig shows those silicon micro needle mechanism structural behaviors in the form of displacement after apply stress on it. Withstanding stress capability of Silicon micro needle shows that the maximum stress value is 7GPa which withstand skin piercing pressure. So it was commented by above comparative study in silicon micro needle deflections were found in the lumen area of the micro needle when stress applied on it up to 3.18MPa and above that. Maximum stress withstand capability of needle is more than the skin resistive force 3.18 MPa. Simulation result shows that if this micro needle design III is made from Silicon material then it is strong enough to penetrate into the human skin without failure because it withstands stress more than 3.18MPa. So from the above simulation results, it is predicted that the proposed micro needle design with the Silicon material is optimal which withstand the bending as well as axial forces during skin insertion.

VI. FLUID FLOW SIMULATION RESULTS OF MICRONEEDLE

The fluidic analysis of the micro-needle was performed considering the Fluid Flow is a Laminar flow. The fluid (considering different types of medicine having different densities and viscosities) was modeled as incompressible, homogeneous and Newtonian. The simulations for different medicines with different densities and viscosities are performed. The simulations show that when the density or viscosity of medicine increases, the flow rate of the medicine in the micro needle decreases, which can be observed in fig. g & h

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CONCLUSIONS

In this presented work design and simulation of micro needles involving finite element analysis technology using comsol 4.2a system. It is use for the application transdermal drug delivery and any fluid extraction from the body. Then, a numerical study method is conducted on a three dimensional model of the hollow micro needle mechanism. That micro needle design was successfully simulated for structural mechanics and concludes appropriate mechanism which withstand with skin resistive force. Also conclude that for which appropriate material presented micro needle get withstand. Fluid flow mechanics conclude that for appropriate mechanism of micro needle, change in fluid velocity causes due to change in density and viscosity. Also it concludes that it withstands for various inlet pressures, and those inlet pressure values best suited with micro pumps which are available in market for integration of micro needle. The maximum buckling and bending force that the micro-needle structures can withstand were simulated. Since the resistive force offered by the human skin was found to be significantly smaller than the maximum buckling and bending forces, it may be concluded that the micro needles which are made up of silicon with given dimensions are capable of penetrating the skin without breakage. Finally it can be established from simulation results that the maximum stress and fluid flow rates were satisfactory for the chosen area of the micro-needle.

The presented work provides useful information and predicted data to simulate optimized design of hollow silicon microneedle for biomedical applications.

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