Numerical simulation of dissolving microneedles for controlled drug delivery

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Numerical simulations provide a short way for a better prediction of the performance of medical devices to design and then fabricate devices with high efficiency. Based on the several advantages of MNs for drug delivery applications, a quantitative method is needed to evaluate their performance prior to fabrication. In this study a single dissolving MN is simulated in COMSOL Multiphysics software to investigate the drug distribution and MN degradation during insertion time. Using the mathematical equations that were developed in the research, which was done by Kim et al, we are able to predict and simulate the microneedle height changes and drug concentration in skin during dissolution time. This framework is applied for the case study of a dissolving PLA MN encapsulating FD70 for ocular treatment. The results revealed that higher drug concentration can be achieved by decreasing the value of pitch size or increasing the drug mass fraction in each needle. By understanding these related factors we are able to get closer to the optimum model.

Among all the methods are available for drug delivery process, microneedle can be as a promising tool for drug administration based on the unique structure, as they are a combination of transdermal patches and hypodermic needles with the effectiveness of hypodermic needle injection and convenience of transdermal patches, they can overcome the limitations that are associated with these two methods that were mentioned above. Microneedles, as their name says, are an array of micron scale needles that are located on a base. These devices are able to disrupt the first layer of our skin, stratum corenum, which is the main barrier to transdermal drug delivery; in that way drugs with high molecular weight like proteins and

peptides have more chance to pass through our skin layers. Microneedles offer an effective way to increase skin permeability in a non-invasive and user friendly manner, so they should be small enough to not reach the blood vessels and nerve endings that are located in deeper tissues, and large enough to be able to carry different drugs with different molecular weights.

Based on their functionality, microneedles can be classified into four general types: solid, coated, dissolving and hollow microneedles. During past years dissolving microneedles have gained a lot of attention, the key feature of this kind of microneedles is that the drug formulation is encapsulated in their structure and will be released as soon as they dissolve off. As they are fabricated of soluble materials or biodegradable polymers, they have the possibility of drug delivery in a controlled manner; it means that the drug delivery rate can be controlled from hours to months based on patients' needs. Another advantage that makes this group of devices a good option for drug delivery is that the drug dose is held by them is much greater than the coated type. By the help of MEMS technology, MN arrays can be fabricated in different sizes and different materials. In dissolving MN the matrix materials, as a drug vehicle, containing active pharmaceutical ingredients (API) is cast on a PDMS master mold. The Rate of MN degradation is directly dependent on the matrix material that was chosen as a structure. We can choose the appropriate one based on our needs, for example materials like PLA or sucrose are dissolved faster in comparison to PLGA polymers, so this difference makes us to choose the PLA or sucrose for the cases that fast dissolution process is needed.

Beside several advantages of MNs that were mentioned above, there is still a need to find a way to increase the efficiency of them in order to reach the most effective drug delivery process. As the first step we have to find the factors that have an effect on their performance. Some works have been done during these years, in terms of skin permeability, and found out that the higher skin permeability and as result higher efficacy can be reached by increasing the number of microneedles in an array, and also the volume of each needle and decreasing patch area. On top of that, pitch, center to center spacing, has a greater effect on MN performance. By decreasing the distance between two adjacent needles, the greater amount of drug can be delivered in our skin layer, but by decreasing the pitch size more force is needed for fully insertion. If the insertion force is not enough, the drug delivery process will not be effective that much. One of the other criteria related to the usage of dissolving MN is the time that is needed for them to be fully dissolved. This time duration is directly dependent on the features of materials that MNs are made of, and the size of each needle. Kim et al have proposed a mathematical model for prediction of the dissolution time and factors that can effect on it. They have used dimensionless mathematical modeling method to show the amount of drug that is delivered during dissolution process.

Conclusion

Recently there is a great interest for the use of dissolving microneedles for medical applications. Due to this fact, there is a need to find a way to understand the dissolution behavior during insertion time. This research tries

to investigate the parameters that can have an effect on dissolution time and drug concentration. The model of dissolving microneedle was simulated, and the drug distribution in skin layers and MN shrinkage can be seen. According to the results, by choosing an appropriate structural material, initial drug concentration and design parameters, the dissolution time and drug concentration can be controlled. The higher amount of drug mass fraction resulted in higher drug concentration and faster dissolution process. Although a greater amount of drug can be delivered from MN array with smaller pitch size, more force should be applied to fully inserted, so it is still challenging to make a balance between them.