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Development of R³ UV Exposure for the UV Dose-Insensitive and Cost-Effective Fabrication of Biodegradable Polymer Microneedles

Authors : Sungmin Park, Gyungmok Nam, Seungpyo Woo, Young Choi, Sangheon Park, Sang-Hee Yoon

Abstract : Puncturing human skin with microneedles is critically important for microneedle-mediate drug delivery. Despite of extensive efforts in the past decades, the scale-up fabrication of sharp-tipped and high-aspect-ratio microneedles, especially made of biodegradable polymers, is still a long way off. Here, we present a UV dose insensitive and cost-effective microfabrication method for the biodegradable polymer microneedles with sharp tips and long lengths which can pierce human skin with low insertion force. The biodegradable polymer microneedles are fabricated with the polymer solution casting where a poly(lactic-co-glycolic acid) (PLGA, 50:50) solution is coated onto a SU-8 mold prepared with a reverse, ramped, and rotational (R3) UV exposure. The R3 UV exposure is modified from the multidirectional UV exposure both to suppress UV reflection from the bottom surface without anti-reflection layers and to optimize solvent concentration in the SU-8 photoresist, therefore achieving robust (i.e., highly insensitive to UV dose) and cost-effective fabrication of biodegradable polymer microneedles. An optical model for describing the spatial distribution of UV irradiation dose of the R3 UV exposure is also developed to theoretically predict the microneedle geometry fabricated with the R3 UV exposure and also to demonstrate the insensitiveness of microneedle geometry to UV dose. In the experimental characterization, the microneedles fabricated with the R3 UV exposure are compared with those fabricated with a conventional method (i.e., multidirectional UV exposure). The R3 UV exposure-based microfabrication reduces the end-tip radius by a factor of 5.8 and the deviation from ideal aspect ratio by 74.8%, compared with conventional method-based microfabrication. The PLGA microneedles fabricated with the R3 UV exposure pierce full-thickness porcine skins successfully and are demonstrated to completely dissolve in PBS (phosphate-buffered saline). The findings of this study will lead to an explosive growth of the microneedle-mediated drug delivery market.

Keywords : R³ UV exposure, optical model, UV dose, reflection, solvent concentration, biodegradable polymer microneedle
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