Non-permanent tattoo application of internet of things three-dimensional printer for beauty-art

Jisu Lee, MS^{1,2} , Abhilash Aditya, PhD^{1,2} , Jihye Kim, BFA³ , Namsoo Peter Kim, PhD^{1,2,3}

¹Department of Metallurgical Materials and Biomedical Engineering, The University of Texas at El Paso, El Paso, TX, United States

²Center for Printable Materials Certificates, The University of Texas at El Paso, El Paso, TX, United States

³Brain Pool Program, K-CBD Center, Korea University, Seoul, Rep. of Korea

Background: The emphasis on non-face-to-face or untact operation services is on the rise due to the ongoing widespread of COVID-19 epidemics, which have caused severe damage worldwide. Untact technology has been applied not only to everyday life but also to the beauty art industry that relies on customer service with contact.

Objective: A safe non-permanent tattoo ink is necessary to overcome the stigma of permanent tattoos and tattoo removal procedures. The purpose of this study is to efficiently deliver non-permanent tattoo ink into the skin through sophisticated untact printing techniques and safe silver compound ink, further minimizing the side effects due to unsanitary conditions.

Methods: Silver-gelatin compound ink serves as an excellent alternative for conventional permanent tattoos with additives. Piston-type extruder (PTE) system and internet of things (IoT) integrated precision-controlled non-permanent and untact system using silver nanoparticle ink.

Results: Complex and sophisticated designs were three-dimensional (3D) printed using a non-permanent tattoo ink containing an optimum concentration of Ag⁺ under 5 N compression force through a 100 µm radius nozzle and diffused up to 200 µm into the stratum corneum through skin contact. Intradermal diffusion simulation and disappearance of the ink within two weeks of the human skin replacement cycle were successfully demonstrated.

Conclusion: The integration of IoT and 3D printers has enabled a hygienic untact tattoo printing technique that has been verified through repeated testing. This study could arouse positive possibilities and interests in the rapidly changing beauty art fields. It provides a new tattoo methodology and further research ideas for the 3D printing applications in tattoo production.

Keywords: nano-silver ink; non-permanent tattoo printing; piston-type extruder printing method; three-dimensional printer; three-dimensional printing

Introduction

A skilled artist or doctor can perform the creative tattoo process with specific qualifications after training. The hygiene of the process and issues of the tattoo itself are evaluated differently based on the times. Adorning the skin with tattoos is a way

of self-expression and is popular of late. Henna has been used for centuries in Hindu and Islamic cultures as a temporary skin tattoo, hair, and nail coloring agent [1]. Henna (2-hydroxy-1, 4-naphthoquinone) is a non-permanent tattoo ink classified as a very low-level sensitizer [2]. However, allergic reactions are often associated with coloring additives in henna [3]. Phenyl-

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Corresponding author: Namsoo Peter Kim

E-mail: nkim@utep.edu

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enediamine (PPD) is one of the additives that facilitates darker color and accelerates the dyeing process of black henna.

PPD is an allergen responsible for contact dermatitis [4-7]. Commercially available black henna contains PPD levels from 3.4 to 51.6 wt% along with heavy metals, such as 0.4–3.1 parts per millions (ppm) of cobalt (Co), 1.1–2.2 ppm of nickel (Ni), 1.6–17.7 ppm of lead (Pb), and 35.0–76.9 ppm of chromium (Cr), further increasing the risk of allergic reactions and contact dermatitis [8]. Hence, an alternative tattoo ink that is safe and simple to use is essential.

Tattoo is an art that requires a specific skill set and is performed by artists. Computer-aided designing (CAD) tools can assist people to create or recreate intricate designs with ease. Equipment such as three-dimensional (3D) printers enables design recreation using CAD and ensures additional employment opportunities for people with basic CAD knowledge. Developing a dedicated non-permanent ink for this process would resolve the discord between autonomy and traditional tattoos that has been for generations. The recent pandemic has made people realize the importance of non-face-to-face contact services (untact services). Further untact procedures may serve as an alternative process for cosmetic enhancement. To achieve this, it is imperative to develop technology and ink for precise printing.

Silver ion (Ag^+) undergoes photoreduction under ultraviolet light to form silver nanoparticles (AgNP), which are stable and biocompatible, making them a viable alternative to the conventional non-permanent tattoo ink [9,10]. Ag^+ and AgNP possess disinfectant, antioxidant, and anticancer properties [11-14]. New skin cells originate from the deepest layers of the skin and gradually rise to the uppermost layer of the stratum corneum. The older skin on the stratum corneum is discarded as part of the skin lifecycle, which is on an average of 14 days in humans [15,16].

The untact non-permanent tattoo procedure demands precise control over the ink dispensing, which can be accomplished by integrating the internet of things (IoT) and extru-

sion or direct writing technology [17-19]. In this study, printing technology using the untact concept has been applied to and demonstrated in the field of nail art. Since the introduction of the first remote 3D nail printing technology, many experiments have been conducted and controlled online between Korea and the United States, and the untact IoT technology is currently in the commercialization stage [20-23]. It is crucial to examine and develop healthy and stable inks suitable for such applications. In addition to the untact printing process, it is important to understand the diffusion of ink into the skin and the parameters affecting the process. This study examined the effects of silver-gelatin compound concentration in ink and contact time on the diffusion rate of Ag^+ and AgNP into the skin.

Materials and methods

Non-permanent tattoo ink preparation

The non-permanent tattoo procedure involves synthesis of silver-gelatin compound ink, piston-type extruder (PTE) 3D printing using silver-gelatin compound ink, and solidification of the printed tattoo ink. Silver compounds and gelatin were procured from a chemical, life science and biotechnology company, Sigma Aldrich, Inc. (St. Louis, MO, USA) various silver-gelatin compound inks were prepared with distilled water and two, five, and ten wt% of silver nitrate. Tattoo duration periods, in other words, the contact duration of the tattoo ink and skin, varied based on silver concentrations in ink. Ten milliliters of distilled water and 0.5 g of gelatin were required to synthesize silver-gelatin compound ink. Gelatin was used to prepare a colloidal solution of silver-gelatin compounds to attain printable consistency using PTE printing technology. Solution concentrations depended on the amount of silver nitrate: 0.34 g for two wt%, 0.85 g for five wt%, and 1.7 g for ten wt% of ink. Various concentrations of silver-gelatin compound ink were produced after mixing the silver nitrate powder, distilled water, and gela-

Fig. 1. The assembled piston-type extruder (PTE) equipment using a pressure and temperature sensor. (A) Wall Mounted 3D Printer, (B) Monkey Bar Style 3D Printer, and (C) schematic image of PTE in the 3D printer with silver-gelatin compound ink.

tin. The solutions were printed using PTE 3D printing technology on a polyester overhead projection (OHP; Fig. 1). After printing the 2D design, the patterned silver-gelatin compound ink on the film was solidified in a freezer at -5°C for 30 minutes.

Several tattoo designs were successfully printed using a wall-mounted monkey bar style 3D printer (Fig. 1). The printers used Arduino, an open-source prototyping platform, and raspberry-pi for precise XYZ-coordinate control. Pressure sensors permitted ultra-precise control of the pressure in the piston-type extruder, enabling accurate print output.

Simulation of diffusion and optimization of printing parameters

PTE deposited non-permanent tattoo ink in the 3D printer ver. 14.2 (Biomedical 3D Printing, Seoul, Korea) by applying a compressive force of five N. The study assigned 0.1, 1, 5, and 10 minutes of contact time of 3D printed tattoo ink patterns on the skin. The diffusion rate depended on Ag^+ and AgNP concentrations and diffusion depth in the skin, and was simulated. Conditions such as moisture content, temperature, and thickness influenced the diffusion rate and tattoo duration.

The first 3D technology applied to the non-permanent ink tattoo field in this study enabled the application of silver-gelatin compound ink to the skin. PTE could efficiently deposit tattoo ink and be easily disposed of after use. This versatility of PTE 3D tattoo printing was favorable for ease of operation. Single line design (SLD) depicts an image using a single line, ensuring constant ink flow through the nozzle with high-viscosity materials [24-26]. The wettability (contact angle at the liquid-solid interface) of the material is crucial as the ink diffuses through the skin. Fick's diffusion law (Fick's 2nd law) governs diffusion through the skin, and is expressed as:

$$\frac{\partial C}{\partial t} = -D \frac{\partial^2 C}{\partial x^2}$$

where c : concentration of Ag^+ and AgNP in tattoo ink, t is time, D is diffusivity, and x is the distance from the skin surface (penetration depth) [27].

Fick's 2nd law determines how diffusion changes the concentration of the ink through time and depth.

Results

Contact angle of tattoo ink

The contact angle of the liquid-solid interface provided a relatively hydrophilic or hydrophobic material among the different concentrations of the non-permanent tattoo ink. A ramehart contact angle goniometer was used to measure the contact angle. The instrument deposited a precise quantity of each concentration onto a platform and measured the contact angle (wet angle) made by the droplet. The wet angles of droplets of two wt%, five wt%, and ten wt% silver compound tattoo inks on the OHP film substrate were measured precisely (Fig. 2). The mean values of the angles were 45.93° (for 2 wt%), 54.43° (for 5 wt%), and 62.83° (for 10 wt%). The measurements suggested that the tattoo ink exhibited both hydrophilic and hydrophobic properties depending on the Ag^+ concentration. Therefore, the addition of Ag^+ manifested a non-spread effect on the OHP films.

Simulation of ink diffusion

In general, diffusion was modeled with the diffusion time and depth as variables and the diffusivity and temperature as constants based on the initial Ag^+ and AgNP concentration and time. Fick's 2nd law of diffusion established the relationship between concentration gradient and time. The diffusion behavior of the tattoo ink with varying Ag^+ and AgNP concentrations over time could be visualized. Fick's 2nd law explained that the diffusion of Ag^+ and AgNP in skin depended on the initial concentrations of ink (0.5, 1.0, 1.5, and 2.0 wt%) and penetration depth (Fig. 3). As shown in Fig. 3, the simulation was conducted

Fig. 2. The images of the droplets of 2 wt%, 5 wt%, and 10 wt% of Ag^+ in solution.

Fig. 3. Simulation of diffusion rates of the silver tattoo ink with different concentrations of Ag^+ (0.5, 1.0, 1.5, and 2.0 wt%), contact time (minutes), and the distance (m) in skins. The representative results show the different rates of the silver tattoo ink under different conditions; Distance-concentration graphs: (A) at contact time 0.1 minutes, (B) at contact time 1 minute, (C) at contact time 5 minutes, and (D) at contact time 10 minutes.

by keeping the diffusivity constant, while contact times and concentrations were varied {Format: $C_{(\text{concentration value})}$ (penetration depth, contact time)} (y-axis) to obtain the corresponding penetration (x) depth (x-axis). The wettability of the silver tattoo ink was favorable within two wt% to ensure proper diffusion through the skin. The data revealed diffusion rates depending on the exact penetrated depth of the ink in skin using different concentrations of silver ink after the contact time. Fig. 3 shows the depth-concentration graph results at contact times of 0.1, 1, 5, and 10 minutes. Different concentrations of Ag^+ were applied to the skin to evaluate penetration rates. The concentration of Ag^+ decreased with increasing contact time, thereby allowing ink to diffuse into the skin.

Observations suggested that the tattoo faded away after following the estimated diffusion rates. The dispersing speed rate (diffusion rate) controls the duration of the projected shape on the stratum corneum and removal speed. Furthermore, longer contact times aided ink diffusion into the skin, resulting in a longer tattoo duration. Based on the results shown in Fig.

3, the contact time changed the concentration of silver tattoo ink as it diffused into the skin. The constant horizontal slope of the graph implied proper diffusion of the ink into the skin with a contact time of 10 minutes as ideal for up to 200 μm , which lasted over the skin cycle (Fig. 3).

Different printing conditions, such as moisture and oil content of skin, thickness, and temperature, were beyond the scope of this study. However, moisturization of the skin 30 minutes before tattoo application yielded the best results. Dyeing of the stratum corneum with the silver tattoo ink compound with a 3D PTE tattoo printer provided a hygienic and economic process for non-permanent tattoos.

PTE 3D printing

The 3D PTE had a unique capability to print detailed designs on an uneven surface, such as nails and skin. This study used 2 wt% of Ag^+ and AgNP in silver-gelatin compound tattoo ink to print non-permanent tattoos. A contact time of 5 minutes (post-printing) indicated a stable tattoo duration of 10 days (Fig. 4).

Fig. 4. Image of the stably projected figure on the nail using 2 wt% of Ag^+ and AgNP in silver-gelatin compound tattoo ink after 5 minutes. The triangle pattern was formed by the piston-type extruder method.

The scale of the print demonstrated precise control of 3D tattoo printing technology.

A complex tattoo design printed on the hand followed the simulated estimations based on the penetration rate and concentration data (Fig. 5). After applying a suitable amount of moisture and oil to the hand, a patterned patch with 0.5 wt% of silver compound ink dyed the skin for 10 minutes (post-printing). Despite washing with water, the tattoo lasted for 11 days. However, as the keratin in the stratum corneum eroded, the tattoo duration decreased.

A non-permanent tattoo with a 0.2 wt% concentration of ink lasted 7 days, confirming the correlation of the silver concentration in the tattoo ink with tattoo duration (Fig. 6). Tattoo duration following Ag^+ and AgNP concentration in the stratum corneum was tested based on parameters such as projection place and stratum corneum's cycle.

The experimental results evaluated the efficacy of non-permanent tattoos using a silver compound. This new process

Fig. 5. Non-permanent tattoos applied on hands using 0.5 wt% of Ag^+ and AgNP in silver-gelatin compound tattoo ink for 10 minutes. (A) Dragon; (B) butterfly.

Fig. 6. Images of a non-permanent star tattoo applied on human skin using 0.2 wt% of Ag^+ and AgNP in the silver-gelatin compound tattoo ink. (A) After 30 minutes; (B) after 7 days.

could be applied for cosmetic applications, analgesics, antibiotics, disinfectants, and esthetic expressions of wounds through drug and ingredient control. Fig. 7 shows the applications of 3D printing in art, applicable to tattoo draft fields. The PTE printing method formed delicate images using hydrophilic ceramic materials, such as clay.

From a different perspective, Fig. 8 shows the artistic applications of 3D printing, which describes imitative 3D printed drafts

of masterpieces, such as the Sehando scene by Jeong-hui Kim (Fig. 8A), the girl with a pearl earring by Johannes Vermeer (Fig. 8B), and Bull by Joong-shop Lee (Fig. 8C). The printed applications preserved the characteristics of the existing masterpieces; however, they were designed by SLD and printed rapidly. SLD resulted in a constant ink deposition rate, leading to a faster printing speed without compromising the esthetics of the design. The ease of continuous ink flow prevented minute distort-

Fig. 7. Unique single line design images of a pattern using hydrophilic ceramic material. (A) Butterfly; (B) leaf; (C) emblem; and (D) rose.

Fig. 8. Single line design recreated images of a pattern using hydrophilic ceramic material. (A) Sehando; (B) the girl with a pearl earring; and (C) Bull.

Fig. 9. Single line design images of a pattern by the optical illusion technique. (A) Image of optical illusion design; (B) image of a pattern using the piston-type extruder method.

tion, causing slight excessive deposition or, in contrast, ensuring perfect printing. In this study, the works of world-famous painters were reinterpreted and recreated into SLD. This would allow anyone to use SLD to personalize tattoos.

Solid Edge, SolidWorks, and Rhino were used to design and print 3D images. These designs were converted into G-code with open source software, such as Cura. From the designer's perspective, 3D SLD is different from regular SLD, as regular SLD repeatedly passes through one point. As they overlap in three dimensions, there is a problem of high viscosity, such as clay injected with silver-gelatin tattoo ink. In this study, the design did not need to pass any point twice. More than 3,000 experiments confirmed the feasibility of applying SLD.

Optical illusion techniques can be applied to 2D designs. Fig. 9 shows that SLD designs appeared to be complex 3D forms with the optical illusion technique, although it is a 2D design. The illusion technique's effect was amplified for tattoos on eyebrows and other hair. The use of 3D printers for tattoos creates opportunities for people with less artistic skill. This study reinterpreted existing artworks and successfully applied them to non-permanent tattoo fields.

Discussion

The contact angles increased with increasing concentrations of Ag^+ and AgNP in the silver-gelatin compound tattoo ink (2 to 10 wt%). The contact angles of two wt%, five wt%, and ten wt% of Ag^+ and AgNP in silver-gelatin compound tattoo ink were 45.93° , 54.43° , and 62.83° , respectively, indicating a shift toward hydrophobic nature with increased silver compound concentration. The hydrophobic nature resulted in less wettability, implying a decrease in the diffusion rate. However, the experimental observations suggested that lower concentrations of Ag^+

and AgNP in silver-gelatin compound tattoo ink were sufficient to print clear and detailed tattoos on the skin. No more than two wt% Ag^+ and AgNP in silver-gelatin compound tattoo ink ensured optimal wettability and diffusion rate, provided adequate contact time on the skin. The experiments repeatedly exhibited the human skin replacement cycle, as all printed tattoos faded within 14 days of application. The study demonstrated various tattoo application procedures, through OHP film to preserve the prints for later use or direct skin printing. Experimental results successfully demonstrated the printing of an optimal concentration of Ag^+ and AgNP in silver-gelatin compound tattoo ink using the PTE 3D tattoo printing method. Repeated experiments concluded that no more than two wt% of Ag^+ and AgNP in the silver-gelatin compound tattoo ink was optimal for tattoo printing. The originality of this study was that the Ag^+ and AgNP in silver-gelatin compound tattoo ink penetrated into a certain thickness of the stratum corneum and faded away along with the old skin at the end of the lifecycle.

The spread of COVID-19 compelled the commercial development of IoT-3D printing technology. This technology can reduce the hazards of a lack of proficiency and hygienic problem of tattoos by using precise design and control of the 3D tattoo printing technology. The untact aspect of tattoo printing eliminates the physical presence of conventional tattoo artists. This ensures a faster hygienic tattoo experience. The use of such automation linked with Web-CLOUD promises remote and faster tattoo printing. CAD software empowers people with no art experience to efficiently operate 3D printers and expands employment opportunities for people with basic CAD knowledge, eliminating the need of highly skilled artists. This study highlighted the cosmetic enhancement of eyebrows using the innovative design of hair illusion through printing. Three-dimensional tattoo printing of silver-gelatin compound tattoo ink

was found to be a safe alternative to conventional black henna, with the additional benefit of protecting skin. The precise control of 3D printing of silver-gelatin compound tattoo ink on the skin was a step closer to wearable electronics for biosensing systems in the future.

In conclusion, the integration of IoT and 3D printers has enabled hygienic and untact tattoo printing, demonstrated through repeated tests. This study demonstrated positive possibilities and interests in the rapidly changing beauty art field. It provided a new tattoo methodology and further research ideas for 3D printing applications in tattoo production.

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Conflicts of interest

The authors have nothing to disclose.

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