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

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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-
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 extrusion 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.](image-url)
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 rame-hart 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.](image-url)
by keeping the diffusivity constant, while contact times and concentrations were varied \(C\) (penetration depth, contact time) \(y\)-axis to obtain the corresponding penetration \(x\)-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 \(\text{Ag}^+\) were applied to the skin to evaluate penetration rates. The concentration of \(\text{Ag}^+\) 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 \(\text{Ag}^+\) 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).
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
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 distor-

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**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.
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

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.
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.

References

1. Puri N, Puri A. A study on contact dermatitis to hair dye and henna. Our Dermatol Online 2013;4:545-8.
2. Thami GP, Kaur S, Kanwar AJ. Allergic contact dermatitis to henna. Allergy 2001;56:1013-4.
3. Pasricha JS, Gupta R, Panjwani S. Contact dermatitis to henna (Lawsonia). Contact Dermatitis 1980;6:288-9.
4. Kang IJ, Lee MH. Quantification of para-phenylenediamine and heavy metals in henna dye. Contact Dermatitis 2006;55:26-9.
5. Jappe U, Hausen BM, Petzoldt D. Erythema-multiforme-like eruption and depigmentation following allergic contact dermatitis from a paint-on henna tattoo, due to para-phenylenediamine contact hypersensitivity. Contact Dermatitis 2001;45:249-50.
6. Brancaccio RR, Brown LH, Chang YT, Fogelman JP, Mafong EA, Cohen DE. Identification and quantification of para-phenylenediamine in a temporary black henna tattoo. Am J Contact Dermat 2002;13:15-8.
7. Mohamed M, Nixon R. Severe allergic contact dermatitis induced by para-phenylenediamine in paint-on temporary 'tattoos'. Australas J Dermatol 2000;41:168-71.
8. Aktas Sukuroğlu A, Battal D, Burgaz S. Monitoring of Law-}

sone, p-phenylenediamine and heavy metals in commercial temporary black henna tattoos sold in Turkey. Contact Dermatitis 2017;76:89-95.
9. Williams NX, Noyce S, Cardenas JA, Catenacci M, Wiley BJ, Franklin AD. Silver nanowire inks for direct-write electronic tattoo applications. Nanoscale 2019;11:14294-302.
10. Huang HH, Ni XP, Loy GL, Chew CH, Tan KL, Loh FC, et al. Photochemical formation of silver nanoparticles in poly (N-vinylpyrrolidone). Langmuir 1996;12:909-12.
11. Nagarajan B, Jairprakasharain GB. Design and application of nano silver based POU appliances for disinfection of drinking water. Indian J Sci Technol 2009;2:5-8.
12. Starovoytov ON, Kim NS, Han KN. Dissolution behavior of silver in ammoniacal solutions using bromine, iodine and hydrogen-peroxide as oxidants. Hydrometallurgy 2007;86:114-9.
13. Ahamed M, Majeed Khan MA, Siddiqui MKJ, AlSalhi MS, Alrokayan SA. Green synthesis, characterization and evaluation of biocompatibility of silver nanoparticles. Physica E 2011;43:1266-71.
14. Nath S, Kalmodia S, Basu B. Densification, phase stability and in vitro biocompatibility property of hydroxyapatite-10 wt% silver composites. J Mater Sci Mater Med 2010;21:1273-87.
15. Kramer O. What is the stratum corneum? [Internet]. San Francisco, CA: Healthline; c2019 [cited 2019 Aug 1]. Available from: https://www.healthline.com/health/stratum-corneum.
16. Lucy H. What is a skin cycle? [Internet]. Leeds: Medifine; c2017 [cited 2019 Aug 1]. Available from: https://www.medifine.co.uk/what-is-a-skin-cycle.
17. Kim NP, Cho D, Zielewski M. Optimization of 3D printing parameters of Screw Type Extrusion (STE) for ceramics using the Taguchi method. Ceram Int 2019;45(2 Pt A):2351-60.
18. Kim NP, Eo J, Cho D. Optimization of piston type extrusion (PTE) techniques for 3D printed food. J Food Eng 2018;235:41-9.
19. Kim NS, Han KN, Church KH. Direct writing technology for 21st century industries - focus on micro-dispensing deposition write technology. Proc Korean Soc Mach Tool Eng Spring Conf 2007;5:511-5.
20. Kim NP, Kim J, Han MS. The convergence of three-dimensional printing and nail-art technology. J Cosmet Med 2019;3:94-101.
21. Park CJ, Aditya A, Kim NP. Conformal projection printing method to increase the accuracy of 3D printed nails. J Cosmet Sci 2020;71:167-78.
22. Kim NP. Internet-of-things nail-printing technology using non-face-to-face contact. J Cosmet Med 2020;4:23-8.
23. Mendoza KL, Ortega A, Kim NS. Optimization of UV LED-curable ink for reverse-offset roll-to-plate (RO-R2P) printing. J Electron Mater 2015;44:784-91.

24. Kim NP, Cepeda B, Kim J, Yue G, Kim S, Kim H. IoT Controlled screw-type 3D food printer using single line design technique. 2018 International Conference on Computational Science and Computational Intelligence (CSCI); 2018 December 12-14; Las Vegas, USA. p. 978-83.

25. Kim S, Kim J, Cepeda B, Kim NP. Single line design technique to improve the accuracy of drug delivery system: piston type extrusion. 2018 International Conference on Computational Science and Computational Intelligence (CSCI); 2018 December 12-14; Las Vegas, USA. p. 709-14.

26. Hong S, Kim N. Synthesis of 3D printable Cu–Ag core–shell materials: kinetics of CuO film removal. J Electron Mater 2015;44:823-30.

27. Fick A. V. On liquid diffusion. Philos Mag 1855;10:30-9.