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Cathodal skin lesions in a tattoo following transcranial direct current stimulation

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Dear Editor,

Transcranial direct current stimulation (tDCS) is a routinely applied neuroscientific method that acts through subthreshold modulation of neuronal membrane potentials [1]. In addition to its principal role in deciphering the physiological correlates underlying perceptual, motor, cognitive, and affective processes in healthy individuals, tDCS has been suggested to provide symptomatic benefits in a number of neurological and psychiatric conditions. When taking into account the necessary precautions and adhering to established administration protocols, tDCS is a safe technique with only mild, transient side effects [2]. Most commonly, these involve itching and tingling sensations, headache, fatigue, and erythema at the site of stimulation. Here, we report the case of an ataxia patient who received ten daily sessions of cerebellar tDCS and ultimately developed skin burns in a tattoo underneath the cathode.

A 47-year-old man participated in a randomized, double-blind, sham-controlled study in which we examined the effects of cerebellar anodal tDCS in 20 patients with spinocerebellar ataxia type 3 [3]. During two consecutive weeks, participants underwent ten daily sessions (2 mA, 20 min, ramp-up and down periods of 30 s each) of either real or sham tDCS, which was delivered by a neuroConn constant current stimulator and two 7 × 5 cm rubber electrodes (current density: 0.057 mA/cm^2; charge density: 685.7 C/m^2 per session). The anode was encased in a dampened sponge envelope, coated with Lectron II electroconductive gel, and placed in the midline 2 cm below the inion. The stimulation site of the cathode was smeared with Ten20 conductive paste to prevent direct skin-electrode contact and was subsequently affixed to the lateral aspect of the right proximal upper limb overlying the deltoid muscle. Time between electrode preparation and start of stimulation was only a few minutes. Patients were sitting on a chair and instructed to avoid sudden movements of the head and arms. Electrodes were secured with elastic gauzes and tape, cleaned after every session, and re-used across subjects. Exclusion criteria were based on the local tDCS screening questionnaire and included age below 16 years, skin disease, pregnancy, history of concussion or brain surgery, and presence of metal or electronic devices anywhere in the body (e.g., clips, fragments, pacemaker, deep brain stimulation systems, vagus nerve stimulator, and cochlear implants) [2]. In addition, use of drugs and history of (other) neurological and psychiatric disorders and syncope had to be recorded and were evaluated on a case-by-case basis. This patient had two tattoos that covered a large part of both proximal upper limbs. Since tattoos are not listed as a contraindication for tDCS application and local skin appeared impeccable, there were no grounds to exclude him for this reason. Impedance levels were maintained below 3 kΩ throughout each of the stimulation sessions during which he only mentioned tingling but no painful sensations. Upon lifting the cathode after the tenth and final tDCS session, we noticed two focal areas of burned skin in the tattoo that were located underneath the electrode's corners (Fig. 1). He was followed up after three, six, and twelve months; both lesions healed with scar formation. Similar injuries were not encountered in any of the other participants. After completion of the full trial, unblinding revealed that he was part of the real tDCS group.

Albeit a rare complication, skin burns have been reported following tDCS administration [4–10]. In the vast majority of cases documented in the literature, including the one presented here, skin tissue underneath the cathode was affected [5,7–10]. This observation may arise from direct current iontophoresis causing alkaline accumulation under the negatively charged electrode. Specifically, positively charged sodium ions react with hydroxyl ions, derived from the reduction of water molecules, to produce sodium hydroxide (NaOH), leading to locally increased basicity and erosion of the epidermis in the unfortunate event of direct skin-electrode contact [11]. Misalignment between the frontal bone's natural curvature and an electrode's flat surface causing focally enhanced current density might theoretically predispose the supraorbital area to developing tDCS-induced skin damage [10], although similar lesions have been described on the upper limb as well [5–7]. Local drying of gel or paste could further increase resistance and non-uniform current distribution across the electrode surface. Other general risk factors for the emergence of electrochemical burns include rectangular electrode shape, prior skin abrasion, use of tap water instead of saline, and a higher number of stimulation sessions [4–10].

To the best of our knowledge, possible harmful effects of low-intensity electrical stimulation on tattooed skin have not been reported thus far. Commonly used screening questionnaires list skin conditions like eczema and psoriasis as relative contraindications but do not specify as to whether people with tattoos at the site of

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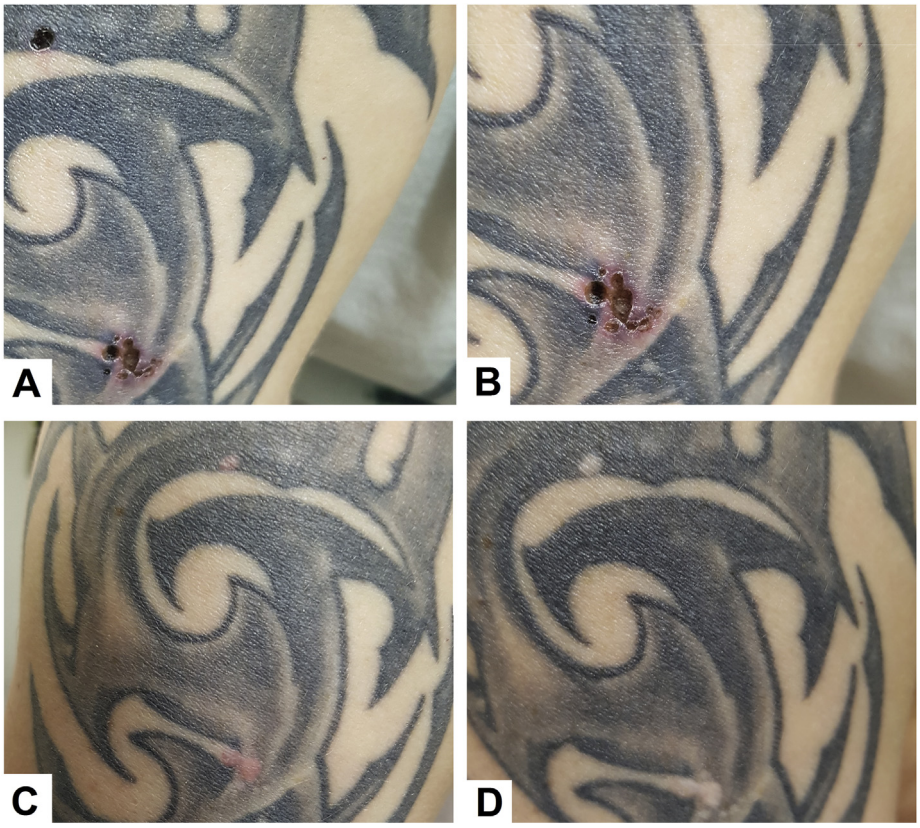

Fig. 1. Skin lesions emerging directly after the tenth tDCS session (A and B) and follow-up after three (C) and twelve months (D).

electrode placement should be excluded from partaking in such studies. Since changing cathode positions in our patient might have altered the distribution of induced electric fields as compared to the other participants, we decided to pursue according to our established protocol. As 1) impedance levels at the skin-electrode interface were kept low throughout stimulation, 2) current density and charge density were well within safety limits, 3) intensity, polarity, and impedance of the tDCS device were independently verified, and 4) none of the other 19 participants experienced similar lesions in any of their 10 sessions, we believe that the chemical composition of the injected tattoo ink may have played a role. Although special care was taken to distribute a sufficiently thick and even layer of conductive paste on the cathode's contact surface, we cannot exclude the possibility that some of it may have crossed on one occasion during stimulation, unintentionally causing direct contact between the rubber electrode and skin.

Tattooing involves the permanent deposition of pigment particles, suspended in a liquid vehicle, into the skin's dermis layer. Iron oxide and carbon are among the common ingredients of black ink. Colored inks, on the other hand, usually have a higher metal content, frequently including cadmium, chromium, cobalt, and copper salts [12]. We hypothesize that the combination of unusually high levels of metallic particles in the dermis and accidental skin-electrode contact during one of the sessions has led to local increases in current densities, thereby catalyzing the excessive formation of NaOH. The fact that lesions in our patient, whose tattoos were placed more than fifteen years before, were observed beneath the cathode's corners is consistent with results from modeling studies showing maximum current density values at an electrode's edges [13]. The present case thus provides a real-life example, similarly illustrating the inhomogeneity of current distribution at the electrode-tissue interface.

In conclusion, our observation suggests that caution should be exercised when applying repeated sessions of tDCS over tattoos, at least when conductive paste is used as contact medium and when it concerns older tattoos with a higher metal content, while one or only a few rounds do not necessarily induce skin damage. Low impedance values throughout stimulation did not prevent the occurrence of skin lesions. Whether the findings in the present report are generalizable to other tDCS settings, such as administration over more recently placed tattoos and usage of saline-soaked sponge electrodes, remains unclear. Nonetheless, in order to raise awareness of this possible complication, we advocate adding the presence of tattoos to tDCS safety screening questionnaires. Avoiding tattooed skin obviously constitutes the most straightforward method to prevent possible complications. When a change in cathode position is not deemed feasible, we argue against the application of creams, soaps, or other alkaline substances before participation and between consecutive sessions. Reasoning from the presumed pathophysiological mechanism outlined above, use of acid-containing cosmetic products could represent an alternative strategy to preserve skin integrity. Finally, we suggest not to administer direct current stimulation over tattoos placed within the last twelve months to ensure optimal skin repair.

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Author contributions

Roderick Maas: conception; drafting and revision of the manuscript.

Bart van de Warrenburg: revision of the manuscript.

Dennis Schutter: conception; revision of the manuscript.

All authors approved the final version of the manuscript.

Declaration of competing interest

Roderick Maas reports no disclosures.

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Roderick P.P.W.M. Maas*, Bart P.C. van de Warrenburg
Department of Neurology, Donders Institute for Brain, Cognition, and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands

Dennis J.L.G. Schutter
Experimental Psychology, Helmholtz Institute, Utrecht University, Utrecht, the Netherlands

* Corresponding author. Radboud University Medical Center, Department of Neurology, Reinier Postlaan 4, 6525 GC Nijmegen, PO Box 9101, 6500 HB Nijmegen, the Netherlands.
E-mail address: roderick.maas@radboudumc.nl (R.P.P.W.M. Maas).

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