JEHS JOURNAL OF EDUCATION, HEALTH AND SPORT

eISSN 2391-8306

OPEN ACCESS

Vol. 95 | Issue 1 |

DOI: 10.12775/JEHS.2026.95.73995

ORIGINAL ARTICLE

The Tattoos and the risk of health complications: a narrative review

Alicja Nierychlewska[1], Michał Falis[2], Alicja Solecka[2], Agata Bronisławska[1], Robert Bronisławski[1], Damian Stencelewski[2], Laura Magdalena Sikorska[3], Magdalena Aleksandra Boniecka[3], Michalina Grudzińska[4]

[1] Nicolaus Copernicus Hospital, Copernicus PL Sp. z o.o., Gdańsk, Poland

[2] University Clinical Center of Gdańsk, Gdańsk, Poland

[3] St. Vincent de Paul Municipal Hospital in Gdynia, Gdynia, Poland

[4] Faculty of Medicine, Medical University of Gdańsk, Gdańsk, Poland

Corresponding author: Alicja Nierychlewska
e-mail: alicjanierychlewska99@gmail.com

ABSTRAKT

Introduction: As tattooing has become a widespread form of body modification, concerns about its health safety have grown. Tattoo inks are mixtures of organic pigments and metal compounds whose toxicological profile after intradermal application remains incompletely understood.
Aim: The aim of this review was to summarise the current knowledge on the health complications of tattooing, spanning dermatological, infectious, pigment-migration and oncological aspects. A second objective was to assess the quality of the available evidence.
Material and method: A narrative review of English-language literature indexed in PubMed and Google Scholar up to December 2025 was performed, including original studies, reviews, case reports and regulatory documents.
Results: Cutaneous complications are best documented - early inflammatory, infectious and allergic reactions, chronic allergy (mainly to red pigment), granulomatous and sarcoidal changes, photo-induced reactions and adverse effects of laser removal. Blood-borne transmission (HBV, HCV, HIV) is linked mainly to non-professional settings; HPV, HSV and rare infective endocarditis also occur. Pigment particles, metals and titanium dioxide may migrate to regional lymph nodes, with scarce data on systemic distribution. Lymphoma findings are divergent and skin cancers within tattoos appear incidental.
Conclusions: Most complications are cutaneous and mild; serious systemic and oncological consequences are rare and not confirmed as direct effects. The main gaps concern ink toxicology and long-term pigment migration, justifying further research, improved regulation and high hygienic and diagnostic standards.

KEYWORDS

tattoo, health complications, tattoo ink, allergic reactions, pigment migration

ARTICLE INFORMATION

Received: 05.07.2026
Revisedsed: 05.09.2026
Accepted: 10.09.2026
Article type: Original Article

LICENSE

This work is licensed under Creative Common Attribution License 4.0 International License CC BY 4.0.

Nierychlewska, A., Falis, M., Solecka, A., Bronisławska, A., Bronisławski, R., Stencelewski, D., Sikorska, L. M., Boniecka, M. A., Grudzińska, M. 2026. The Tattoos and the risk of health complications: a narrative review. Journal of Education, Health and Sport, 95(1): 73995. DOI: 10.12775/JEHS.2026.95.73995

© The Authors 2026

1. Introduction

Over recent decades, tattooing has ceased to be a phenomenon characteristic only of specific social groups and has become a common form of body modification in Western countries [1]. This trend is reflected in successive Harris Poll surveys conducted in the United States, which showed an increase in the prevalence of tattoos in the general population from 16% in 2003 to 21% in 2012 [2]. A further rise in the popularity of tattooing was recorded in subsequent years. An Ipsos survey conducted in 2019 showed that 30% of adult Americans had at least one tattoo, compared with 21% in 2012 [3]. A particularly high prevalence of tattoos is observed among young adults. In the Ipsos survey, at least one tattoo was reported by 40% of people aged 18-34 years, compared with 16% of those aged 55 years and older [3]. Along with the growing popularity of tattoos, the motivations associated with obtaining them are also changing [4]. In a study conducted among tattooed individuals in Poland, the most frequently indicated functions of a tattoo were expressing one's own personality, enhancing sexual attractiveness, and perceiving it as a form of art, while tattoos were less often associated with provocation or belonging to a particular subculture [4]. As the number of tattooed people increases, growing attention is being paid to the potential health consequences associated with the tattooing [5]. In a nationwide survey conducted in German-speaking countries, 7.7% of respondents reported complaints still present 4 weeks after obtaining a tattoo, while 6.0% reported persistent skin problems related to the tattoo [5].

To understand the mechanisms responsible for these complications, a brief description of the tattooing process is necessary. Tattooing consists of introducing pigment into the dermis by means of repeated punctures made with ink-coated needles [6]. The dye is deposited at a depth of approximately 1.5-2 mm, mainly in the papillary layer of the dermis [6]. It has also been shown that some pigment particles may travel beyond the site of administration and reach regional lymph nodes [6]. The chemical composition of inks used for tattooing is diverse and includes both organic pigments and inorganic metal compounds [7]. One of the most commonly used ink components is titanium dioxide (TiO_2), used to obtain specific shades when mixed with other dyes [7]. Tattoo inks may also contain metals such as nickel, chromium, and cobalt, which are components of pigments or are present as impurities of the manufacturing process [7]. With the growing popularity of tattoos, increasing attention is being paid to the safety of the inks used to produce them [8]. Many pigments used in tattoo inks were originally developed for industrial applications, such as the production of varnishes, printing inks, or plastics, rather than for administration into the human body [9]. The safety of these substances when used for tattooing has not yet been assessed toxicologically [9]. Consequently, attention has been drawn to the need to develop effective regulations concerning the components of inks used for tattooing [8]. For many years, however, tattoo inks were not subject to uniform, specific regulations at the European Union level, and the applicable provisions did not ensure full control of the safety of inks and the impurities they contain [8]. The need to introduce mandatory regulations led to the development of restrictions on substances used in tattoo and permanent make-up inks under the REACH Regulation [8]. Despite progress in the regulation of tattoo inks, significant gaps remain in knowledge about the safety of their components and the mechanisms responsible for the development of adverse effects [8]. The most frequently described complications include local inflammatory reactions, contact dermatitis, infections, and allergic reactions, although rarer systemic effects have also been reported [8,9].

2. Methodology

This work is a narrative review of the current literature on the health complications associated with tattooing. To achieve the objectives of the work, a literature review was conducted using the PubMed and Google Scholar databases, covering publications published up to December 2025.

The search strategy was based on keywords and their combinations, including, among others: „tattoo", „tattoo complications", „tattoo ink", „tattoo pigments", „allergic reactions", „infectious complications", „toxicology", „lymph node migration", and „REACH regulation". The analysis covered publications on the epidemiology of tattooing, the composition and safety of tattoo inks, the applicable legal regulations, and the health complications associated with tattooing, with particular emphasis on dermatological and infectious complications, the phenomenon of pigment migration, and the potential oncological risk.

Publications in English were included, with particular emphasis on clinical studies, epidemiological studies, review articles, case reports, and regulatory documents. Preliminary selection was based on the analysis of titles and abstracts for consistency with the aim of the work, after which the full texts of the selected publications were evaluated. Additional sources

DOI: 10.12775/JEHS.2026.95.73995

were identified through analysis of the literature cited in the included articles.

The main groups of health complications associated with tattooing, discussed in detail in the following sections, are summarised in Table 1.

Table 1. Overview of the main groups of health complications associated with tattooing

Complication group	Examples	Typical time of onset	Section
Early dermatological	Inflammatory response, bacterial infections, early allergic reactions	days-weeks	3.1
Late and chronic dermatological	Allergic reactions (especially to red pigment), granulomatous and sarcoidal changes, photo-induced reactions	months-years	3.2
Related to laser removal	Pigmentary disturbances, erythema, blistering; in addition, formation of pigment degradation products with potentially harmful effects	after the procedure (early and persistent symptoms)	3.3
Infectious	Bacterial infections, non-tuberculous mycobacteria (NTM), HBV/HCV/HIV, HPV, HSV, infective endocarditis	days-years (depending on the pathogen)	4
Pigment migration	Pigment deposition in regional lymph nodes, potential systemic distribution	chronic (persistent)	5
Oncological	Lymphomas; melanoma and other skin cancers	years (hypothetical association)	6

Abbreviations: NTM – non-tuberculous mycobacteria; HBV – hepatitis B virus; HCV – hepatitis C virus; HIV – human immunodeficiency virus; HPV – human papillomavirus; HSV – herpes simplex virus.

3. Dermatological complications

Dermatological complications constitute an important group of adverse effects associated with tattooing [10]. They may occur both immediately after the procedure and develop many months or years after it [10]. Their clinical picture is diverse and includes, among others, transient inflammatory reactions related to the healing process, infections, allergic reactions, granulomatous changes, and exacerbation of existing skin diseases [10,11].

3.1 Early complications

3.1.1 Early inflammatory reaction

Immediately after obtaining a tattoo, transient local changes are often observed, including pain, redness, and swelling of the skin [11]. These symptoms are usually self-limiting and resolve within a few weeks during the healing process [11]. Their occurrence is associated both with the mechanical damage to the skin during tattooing and with the presence of substances used during the procedure, including ink components and diluents [11]. The skin damage associated with tattooing triggers a series of changes occurring within the tissues. One of the first stages is the development of oedema and the influx of immune cells to the tattooing site [6,10]. The early, physiological inflammatory response should be differentiated from bacterial infection, which, due to its infectious nature, is discussed in the section on infectious complications.

3.1.2 Early allergic reactions

The diagnosis of allergic reactions associated with tattooing remains a significant diagnostic challenge. Various forms of hypersensitivity to ink components have been described in the literature, but the degree of confirmation of their allergic basis varies [12].

Allergic contact dermatitis (ACD) is an immunological complication associated with tattooing [13]. This reaction develops through a type IV hypersensitivity mechanism and may appear either within a few days of obtaining a tattoo or many months or years after the procedure [12,13]. The risk of its occurrence depends, among other things, on prior sensitisation to a given ink component and on processes occurring after the implantation of the pigment in the skin, such as its degradation or metabolic transformation [12].

Potential allergens associated with the development of ACD include, among others, nickel compounds, methylisothiazolinone, formaldehyde, and p-phenylenediamine [13,14]. Clinically, allergic reactions most often involve the areas containing a particular pigment colour and may manifest as itching, swelling, and papular, plaque-like, lichenoid, or hyperkeratotic changes [12,15]. In some cases, the clinical picture may resemble a skin and soft-tissue infection, which makes a correct diagnosis difficult [13].

Rarer forms of hypersensitivity have also been described, such as contact urticaria and photoallergic reactions associated with the presence of specific ink components [12,15]. In isolated cases, skin test results suggested the involvement of IgE-dependent mechanisms, and cases of anaphylaxis developing after obtaining a tattoo have also been reported in the literature [11,12].

3.2 Late and chronic complications

3.2.1 Chronic allergic reactions – the problem of red pigment

Chronic allergic reactions are among the best-documented late complications associated with tattooing [16]. They particularly often involve red pigments and their shades, such as pink, orange, purple, or maroon [16].

In contrast to early hypersensitivity reactions, these changes may develop after many weeks, months, or even years after obtaining a tattoo [12]. Historically, these reactions were associated mainly with the presence of cinnabar (mercury sulphide, HgS), whereas increasing attention is now being paid to the role of organic azo pigments used in red tattoo inks [12,16].

The clinical picture is diverse but most often includes itching, swelling, skin thickening, and papular or hyperkeratotic changes limited to the area containing a particular pigment [10,16]. Histopathological examinations do not reveal a single characteristic pattern of allergic reactions associated with tattoos. Lichenoid, granulomatous, and sarcoidal changes within the dermis have been described, as well as patterns resembling cutaneous lymphoma (pseudolymphoma). Changes affecting the epidermis, such as acanthosis or spongiosis, are observed less frequently [16].

The treatment of chronic allergic reactions remains difficult. Topical or intralesional glucocorticosteroids are most commonly used, while in treatment-resistant cases removal of the pigment or surgical excision of the lesion may be necessary [17].

3.2.2 Granulomatous reactions and sarcoidosis

Granulomatous reactions are among the chronic immune responses observed within tattoos. Among them, foreign-body granulomas predominate, which should be differentiated from both allergic reactions and sarcoidal changes [12,18]. Foreign-body granulomas arise in response to the presence of pigment particles persisting in the skin. The pigment may be recognised by the immune system as foreign material, leading to the recruitment of macrophages and the formation of granulomas intended to wall off this material from the surrounding tissues [19]. On histopathological examination, foreign-body granulomas consist of epithelioid cells, lymphocytes, and giant cells containing pigment particles [15,17]. Treatment of granulomatous reactions is aimed primarily at limiting the chronic inflammation. Therapy involves potent topical glucocorticosteroids or intralesional corticosteroid injections. If the lesions persist, removal of the factor sustaining the inflammatory reaction may be necessary [17].

A particular form of granulomatous reactions observed within tattoos are sarcoidal reactions. Granulomatous changes developing in a tattoo may represent a manifestation of systemic sarcoidosis, involving, among others, the lungs and the eye [12]. Clinically, sarcoidal reactions may manifest as multiple firm papules or nodules developing within the tattooed skin [20]. These reactions may show considerable similarity to sarcoidosis in terms of both the clinical and the histopathological picture [19].

The relationship between tattoo-associated sarcoidal reactions and systemic sarcoidosis remains a matter of debate. Some authors consider them a separate disease entity, while others indicate that they may represent an early manifestation of systemic sarcoidosis, preceding the development of full-blown disease [19].

The clinical significance of this phenomenon is confirmed by data presented by Antonovich and Callen [20]. In a review of 19 reported cases, a tattoo-associated sarcoidal reaction led to a diagnosis of systemic sarcoidosis in 14 patients [20]. Sarcoidal reactions may involve either many pigment colours or be limited to a single colour. For this reason, involvement of only a specific pigment does not allow sarcoidosis to be unambiguously distinguished from an allergic reaction [20].

It is suggested that chronic exposure of the immune system to substances contained in the tattoo pigment may play a role in the manifestation of sarcoidosis in genetically predisposed individuals [20]. For this reason, the presence of sarcoidal changes within a tattoo

DOI: 10.12775/JEHS.2026.95.73995

should prompt further investigation for involvement of other organs, since cutaneous manifestations may precede the diagnosis of systemic disease or remain its only symptom [20].

3.2.3 Photosensitisation and phototoxic reactions

Photo-induced reactions are among the less frequently described chronic complications associated with tattooing. They may develop after exposure of tattooed skin to solar radiation and manifest with local inflammatory symptoms [21,22].

Photoallergic reactions associated with the presence of specific pigments in tattoos have also been described in the literature [12].

Historically, particular attention was paid to yellow pigments containing cadmium sulphide, which has phototoxic properties [22,23]. In Bjornberg's classic study, oedema within the tattoo after exposure to sunlight occurred in 18 of 24 people with yellow tattoos. Similar reactions were also observed in some patients with red pigments containing small amounts of cadmium [22].

More recent studies indicate, however, that complaints related to sun exposure are not limited to yellow pigments. In the study by Hutton Carlsen and Serup involving 144 people with tattoos, symptoms related to sun exposure were reported by 31 participants, which constituted more than half of all those reporting any tattoo-related complaints [21]. These reactions most often manifested as swelling, itching, burning, pain, and redness of the skin [21]. The authors found that complaints related to solar radiation occurred mainly within black, red, and blue tattoos [21].

3.3 Complications associated with laser tattoo removal

The growing number of people obtaining tattoos also translates into increased interest in procedures for their removal [24]. For many years, the basic method of laser tattoo removal consisted of devices using Q-switched technology [24]. The effectiveness of this method, however, depends on the properties of the pigment used, and some colours remain difficult to remove completely [24]. For this reason, increasing attention is being paid to picosecond lasers, which may increase the efficacy of tattoo removal procedures [24]. The action of lasers used for tattoo removal is based on the phenomenon of selective photothermolysis, in which short pulses of radiation are preferentially absorbed by pigment-containing cells, leading to their thermal damage [25]. After absorbing the laser energy, the dye particles undergo rapid heating and break up into smaller fragments [26]. The resulting products can then be phagocytosed by macrophages and fibroblasts and transported via lymphatic vessels, contributing to the gradual removal of pigment from the skin [24,25]. Despite the effectiveness of laser tattoo removal, increasing attention is being paid to the safety of the products formed during pigment degradation. It has been shown that under the influence of laser radiation, organic pigments, in particular azo pigments, may decompose into numerous chemical compounds with potentially unfavourable biological effects [26]. Among the identified degradation products are, among others, 2-amino-4-nitrotoluene, 3,3'-dichlorobenzidine, and o-toluidine, classified as aromatic amines with potential carcinogenic activity [26]. Moreover, it has been shown that the laser degradation of some pigments may lead to the formation of benzene and hydrogen cyanide [7]. At the same time, the available toxicological data on many pigments used in tattoos remain limited [26]. The significance of these observations is not limited to the site of laser action. It has been shown that fine pigment particles can be transported to regional lymph nodes, where elements associated with pigments, such as nickel, chromium, and cadmium, were also detected [7]. These observations indicate that the effects of pigment degradation and elimination are not limited to the site of the procedure, and that this process may lead to the accumulation of pigment particles and associated elements beyond the skin [7]. Despite the high effectiveness of laser tattoo removal, this procedure is not without adverse effects. The most frequently described complications include skin pigmentation disorders in the form of hypo- and hyperpigmentation, as well as transient erythema, swelling, blistering, and procedure-related pain [24,27].

4. Infectious complications

4.1 Bacterial infections

In contrast to the physiological inflammatory response, which gradually subsides during healing, bacterial infections usually develop within a few days of obtaining a tattoo [28]. Among the bacterial infections associated with tattooing most frequently described in the literature are cellulitis and skin abscesses [28]. Acute purulent infections are caused primarily by Staphylococcus aureus (both MSSA and MRSA strains), less often by Streptococcus species and Pseudomonas aeruginosa [28]. In the analysis conducted by Dieckmann et al., S. aureus was the most frequently isolated aetio-

logical agent and was responsible for 81% of the reported cases of tattoo-associated bacterial infection [28].

4.2 Infections caused by non-tuberculous mycobacteria (NTM)

An important group of tattoo-associated infections are those caused by non-tuberculous mycobacteria (NTM). Cases of such infections developing after obtaining a tattoo are increasingly described in the literature, most often associated with the species Mycobacterium chelonae and Mycobacterium abscessus [28]. In contrast to typical bacterial infections, which usually appear within a few days of the procedure, NTM infections most often become apparent after several weeks, and sometimes even months, after obtaining a tattoo [28]. Skin lesions may appear as early as 7-21 days after the procedure, while new eruptions may be observed for a further 1-4 months [29]. The clinical picture most often includes chronic papular, pustular, or nodular lesions limited to the tattoo area [28,29]. In the reported cases, standard empirical treatment did not bring clinical improvement, which may make rapid diagnosis of the infection difficult [29]. The most likely source of infection is considered to be primarily the use of non-sterile water to dilute the ink, as well as contamination of the dye preparation itself [28,29]. In the case of persistent skin lesions within a freshly obtained tattoo, a skin biopsy together with microbiological testing for NTM is recommended [29].

4.3 Blood-borne viral diseases – HBV, HCV, HIV

One of the most serious infectious complications associated with tattooing is the possibility of transmission of blood-borne pathogens, primarily hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV) [30]. The tattooing process involves repeated puncturing of the skin with a needle, which, if contaminated equipment is used or disinfection is performed improperly, may create conditions for the transmission of infection [30]. Particular attention is paid to HCV infections, as this virus is transmitted mainly through percutaneous contact with infected blood [31]. Analysis of the available studies has shown that the risk of HCV infection depends largely on the conditions in which the tattoo is performed [31]. No clear evidence was found indicating an increased risk of infection in the case of tattoos performed in professional, supervised studios [31]. A higher risk was observed, however, in situations where tattoos were performed in non-professional settings, including private homes or prisons [31]. These results are confirmed by more recent epidemiological studies. In an analysis conducted within the French Constances study, obtaining tattoos outside professional studios was associated with a more than fourfold higher risk of HCV infection (HR 4.14; 95% CI 2.33-7.35), while obtaining tattoos outside countries with appropriate sanitary regulations was associated with an increased risk of HBV infection (HR 3.22; 95% CI 1.39-7.44) [32]. Additional data are provided by the meta-analysis by Lim et al., covering 121 studies assessing the relationship between tattooing and the occurrence of blood-borne diseases [30]. The authors demonstrated a higher frequency of HCV infections among tattooed people compared with people without tattoos (OR 2.37; 95% CI 2.04-2.76) [30]. The same analysis also found an increased frequency of HBV (OR 1.55; 95% CI 1.31-1.83) and HIV (OR 3.55; 95% CI 2.34-5.39) infections in the population of tattooed people [30]. In the case of HBV, the risk of transmission is currently partly limited by widespread protective vaccination programmes, which have contributed to a significant reduction in the frequency of infections in many countries [33]. The results concerning HIV should, however, be interpreted with caution. Lim et al. point out that some behaviours associated with an increased risk of infection, such as a greater number of sexual partners or the use of psychoactive substances, may occur more frequently in the tattooed population and partly influence the observed associations [30]. Regardless of the type of pathogen, adherence to the principles of asepsis, the use of single-use equipment, and appropriate sanitary control of premises performing such procedures are of key importance in the prevention of blood-borne infections associated with tattooing [31].

4.4 HPV, HSV, and other rare infectious complications associated with tattooing

In addition to blood-borne infections, rarer infectious complications associated with tattooing have also been described in the literature, including infections with human papillomavirus (HPV), herpes simplex virus (HSV), and sporadic cases of infective endocarditis [34,35]. One of the best-documented viral skin complications are viral warts developing within a tattoo [34]. Cases of both common warts (verruca vulgaris) and flat warts (verruca plana) developing within a tattoo have been described. In the available case reports, viral warts were more often located in areas made with black ink than within coloured tattoos or non-tattooed skin [36]. A characteristic feature of these lesions is a long latency period – the average time from obtaining a tattoo to the appearance of lesions is about 5 years [37]. The mechanism of their formation has not been unambiguously explained. One proposed hypothesis assumes HPV infection during tattooing through contaminated instru-

DOI: 10.12775/JEHS.2026.95.73995

ments, ink, the tattoo artist's saliva, or autoinoculation of the virus from an existing wart present on the skin of the tattooed person [36]. The authors point out, however, that the inoculation theory alone does not fully explain the observed predilection of lesions for specific areas of the tattoo, especially those made with black ink [36]. An alternative explanation is the concept of the so-called immunocompromised district proposed by Ruocco et al., according to which areas of skin subjected to prior trauma or other damaging factors may show persistent disturbances of the local immune response, favouring the development of infections limited to a given area of skin [38]. With regard to tattoos, it is suggested that local changes in the immune response may facilitate the development of HPV infection within tattooed skin [36,37]. Cohen et al. additionally draw attention to the possibility of the virus being transmitted by the tattoo artist as a result of contact with a wart present on an uncovered hand, and to the potential transmission of HPV through saliva used to dilute pigment during tattooing [34]. Isolated cases of infection or reactivation of herpes simplex virus associated with tattooing have also been described in the literature [34]. In the reported cases, the lesions appeared within a few days of obtaining the tattoo and consisted of vesicular eruptions developing within the tattooed skin [34,39]. Cases have been described in which obtaining a tattoo preceded the reactivation of a previously experienced HSV infection, suggesting that the procedure may act as a triggering factor for recurrence of the infection in infected individuals [39]. Among the extremely rare but potentially severe complications are cases of infective endocarditis observed after body-art procedures, including tattooing [35]. Armstrong et al. emphasise that this complication occurs sporadically but may lead to a severe clinical course, especially in people with existing heart defects [35]. For this reason, in people with heart defects belonging to groups at increased risk of infective endocarditis, the potential risks associated with the procedure should be taken into account before obtaining a tattoo. The possibility of using antibiotic prophylaxis in selected groups of patients has also been described in the literature [35].

5. Tattoo pigment migration and systemic distribution

Although tattoo pigments are introduced into the skin with the intention of achieving a permanent aesthetic effect, they do not remain solely at the site of administration [7]. After obtaining a tattoo, some of the pigment particles are taken up by phagocytic cells and may be transported via lymphatic vessels to regional lymph nodes [7]. Direct evidence of pigment migration was provided by the study conducted by Schreiver et al., in which skin samples and the corresponding regional lymph nodes of tattooed people were analysed [7]. The authors demonstrated the presence of the same pigments in both the skin and the lymph node tissue, confirming their movement from the site of administration to the lymphatic system [7]. Moreover, the simultaneous transport not only of organic pigments but also of heavy metals and titanium dioxide (TiO_2) particles to regional lymph nodes was demonstrated [7]. In the regional lymph nodes, the presence of TiO_2 particles was found, as well as elements such as nickel and chromium, which may occur as components or impurities of tattoo inks [7]. The authors also observed that smaller pigment particles were more frequently detected in the lymph nodes than larger aggregates, suggesting that particle size may play an important role in the migration process [7].\

Migration of pigments to the lymph nodes was described in the literature even before the use of modern analytical methods [7]. Anderson et al. presented the case of a patient with melanoma in whom, during lymphadenectomy, enlarged, darkly pigmented lymph nodes were found, raising suspicion of metastatic disease [40]. Histopathological examination, however, did not reveal metastatic disease, and the pigment present in the nodes turned out to originate from a previously obtained tattoo [40]. This observation indicates that the deposition of tattoo pigments in the lymph nodes may constitute a significant diagnostic challenge, particularly in patients being evaluated for cancer [40]. The biological significance of the long-term accumulation of pigments in the lymph nodes remains incompletely understood. In the study by Schreiver et al., ultrastructural changes were observed in the tissues adjacent to the deposited pigment particles, but their biological significance remains unclear [7]. At present, however, there are insufficient data to allow an unambiguous assessment of the clinical consequences of these observations. The available data concerning the further distribution of pigments beyond the lymphatic system are considerably more limited. In an experimental study conducted on mice, Sepehri et al. demonstrated the presence of pigment particles in the Kupffer cells of the liver [41]. This observation suggests the possibility of some ink components moving to distant organs via the bloodstream [41]. The authors emphasise, however, that these observations come from an animal model and that their significance for human health remains unclear [41]. The available data indicate that some tattoo pigments may move beyond the site of administration and become deposited in regional lymph nodes, and potentially also in other tissues of the body [7,41]. At the same time, the number of studies on the long-term

effects of pigment migration beyond the skin remains limited, which is why the actual biological consequences of this phenomenon require further research.

6. Oncological risk associated with tattooing

6.1 Tattoos and lymphomas

In recent years, interest has grown in the potential relationship between tattooing and the risk of developing lymphomas [42,43]. Interest in this issue stems, among other things, from the observation that some tattoo ink components may migrate to regional lymph nodes, where they persist for a long time after the procedure [7]. A summary of the most important epidemiological studies assessing the relationship between tattooing and the risk of lymphomas is presented in Table 2.

One of the most important studies assessing this relationship was the Swedish case-control study conducted by Nielsen et al., involving 11,905 participants [42]. The authors demonstrated that people with tattoos had a higher risk of developing malignant lymphoma than non-tattooed people (IRR 1.21; 95% CI 0.99-1.48) [42]. The highest risk was observed in the period of less than two years after obtaining the first tattoo (IRR 1.81; 95% CI 1.03-3.20) [42]. In the analysis of lymphoma subtypes, the highest risk values were recorded for diffuse large B-cell lymphoma and follicular lymphoma [42]. The authors emphasised, however, that no relationship was observed between the size of the area covered by tattoos and the risk of disease [42]. Similar observations were presented in the Danish twin study published by Clemmensen et al. [44]. The authors demonstrated an increased risk of lymphoma in people with large tattoos exceeding the area of the palm (HR 2.73; 95% CI 1.33-5.60) [44]. The authors noted, however, that the mechanisms responsible for the observed relationship remain unclear and require further research [44]. Different results were obtained, in turn, in the American case-control study conducted by McCarty et al. [45]. The analysis did not show an unambiguous relationship between having a tattoo and the overall risk of Hodgkin and non-Hodgkin lymphomas [45]. The authors did, however, note elevated odds ratios for some rarer subtypes of lymphoproliferative cancers [45]. This relationship was most evident in people who had obtained a tattoo more than 10 years earlier [45]. The most recent systematic review and meta-analysis conducted by McConnell et al. did not show a statistically significant relationship between tattooing and the development of non-Hodgkin lymphomas [43]. The authors emphasised, however, that the available data are characterised by limited methodological quality and considerable heterogeneity [43]. The current state of knowledge therefore does not allow confirmation of a cause-and-effect relationship between tattooing and the development of lymphomas. The available epidemiological studies indicate, however, the possible existence of such a relationship, especially with regard to selected lymphoma subtypes, which justifies the need for further research [42-44].

6.2 Tattoos and melanoma and other skin cancers

Isolated cases of skin cancers developing within tattoos have been described in the literature for many years [46]. They most often concern malignant melanoma, basal cell carcinoma (BCC), squamous cell carcinoma (SCC), and keratoacanthoma [46]. Interest in this issue

Table 2. Summary of epidemiological studies assessing the relationship between tattooing and the risk of lymphomas

Study (year)	Study type	Population (n)	Country	Main endpoint	Risk measure (95% CI)	Authors' conclusion
Nielsen et al. (2024) [42]	Population-based case-control	11,905 (1,398 cases / 4,193 controls)	Sweden	Malignant lymphoma	IRR 1.21 (0.99-1.48); <2 years from first tattoo: 1.81 (1.03-3.20); DLBCL: 1.30 (0.99-1.71)	Increased risk; causality requires confirmation
Clemmensen et al. (2025) [44]	Twin study (cohort and case-co-twin)	2,367 (cohort) / 316 (case-co-twin)	Denmark	Lymphoma – tattoos larger than the palm	HR 2.73 (1.33-5.60); without size adjustment: no effect (HR 1.35; 0.68-2.71)	Increased risk for large tattoos
McCarty et al. (2024) [45]	Population-based case-control	9,020 (820 cases / 8,200 controls)	USA (Utah)	Non-Hodgkin lymphoma (NHL) overall	OR 0.83 (0.61-1.11); rare B-cell NHL (20-60 years): 2.06 (1.01-4.20)	No overall association; signal for rarer subtypes
McConnell et al. (2025) [43]	Systematic review and meta-analysis	17,941 (4 observational studies)	Meta-analysis (various countries)	Non-Hodgkin lymphoma (pooled OR)	OR 1.01 (0.82-1.24); FL: 1.01 (0.77-1.33); DLBCL: 0.89 (0.54-1.46)	No significant association; low quality of evidence

Abbreviations: IRR – incidence rate ratio; OR – odds ratio; HR – hazard ratio; CI – confidence interval; NHL – non-Hodgkin lymphoma; DLBCL – diffuse large B-cell lymphoma; FL – follicular lymphoma.

DOI: 10.12775/JEHS.2026.95.73995

stems both from the reported cases of cancers developing within tattoos and from questions concerning the long-term safety of tattoo pigments [46]. In the review conducted by Kluger and Koljonen, a total of 50 cases of skin cancers developing within tattoos were identified, including 23 cases of squamous cell carcinoma or keratoacanthoma, 16 cases of melanoma, and 11 cases of basal cell carcinoma [46]. The authors emphasised, however, that the number of described cases remains small compared with the number of people with tattoos worldwide [46]. On the basis of the available data, no evidence was found to consider a tattoo an independent risk factor for the development of skin cancers, and the authors considered the observed relationship to be probably incidental [46]. These conclusions are confirmed in newer analyses concerning melanoma developing within tattoos. In the literature review conducted by Brusasco et al., 43 published cases of melanoma developing within tattooed skin were identified, and after including two new cases of their own, this number rose to 45 [47]. The most common location of the lesions was the upper limbs and the trunk, and most cases concerned tattoos made with black or blue pigment [47]. The authors emphasised, however, that the small number of described cases argues rather for an incidental co-occurrence of melanoma and tattoos than for the existence of a direct causal relationship [47]. A significant clinical problem, on the other hand, may be the impeded diagnosis of cancerous lesions developing within tattooed skin [47]. Benandi et al. point out that tattoo pigment may impede both the clinical and the dermoscopic assessment of pigmented lesions [48]. As a potential solution to these difficulties, Brusasco et al. indicated the use of reflectance confocal microscopy (RCM) in combination with dermoscopy, emphasising that this method may increase the diagnostic accuracy of melanocytic lesions and facilitate the differentiation of melanocytic cells from exogenous tattoo pigment, which may reduce the risk of diagnostic errors [47]. In turn, Benandi et al. demonstrated that the cases of melanoma developing within tattoos described in the literature were characterised by a greater average Breslow thickness and a higher proportion of invasive lesions at the time of diagnosis than is observed in large population-based melanoma studies, which may suggest a risk of delayed diagnosis [48]. The current state of knowledge does not allow confirmation of a cause-and-effect relationship between tattooing and the development of melanoma or other skin cancers [46,47]. The available data indicate, however, the need for further epidemiological research and for maintaining particular diagnostic vigilance in the case of pigmented lesions developing within tattoos [47,48].

6.3 Potential carcinogenic mechanisms

Despite growing interest in the potential relationship between tattooing and the development of cancers, the biological mechanisms that might account for the observed epidemiological associations have not yet been elucidated [42]. One of the considered mechanisms is the long-term exposure of tissues to compounds with potential carcinogenic activity present in some tattoo pigments and to their transformation products [46]. Particular interest is attracted by the products formed as a result of the photodegradation of pigments under the influence of UV radiation and during laser tattoo removal [46]. The available data do not currently allow an unambiguous determination of the clinical significance of the proposed carcinogenic mechanisms in humans [9]. Another mechanism under consideration is chronic stimulation of the immune system associated with the presence of pigments in the body [42]. The authors indicate that disturbances of the immune response may play a role in the pathogenesis of lymphomas, but the involvement of tattoo pigments in this process has not yet been proven [42]. The currently proposed mechanisms are hypothetical in nature and do not allow confirmation of a cause-and-effect relationship between tattooing and the development of cancers [46].

7. Summary

In recent decades, tattooing has become a common form of body modification, and the growing popularity of the procedure is accompanied by increasing attention to its potential health consequences. The literature review conducted shows that the spectrum of complications associated with tattooing is broad, but their frequency, severity, and degree of documentation remain highly variable.

The best-known and most frequently described group are dermatological complications. They include both transient early reactions (inflammatory response, bacterial infections, early allergic reactions) and late and chronic complications, including allergic reactions associated primarily with red pigment, granulomatous and sarcoidal reactions, and rarer photo-induced reactions. A separate category is formed by complications associated with laser tattoo removal, where, alongside pigmentation disorders, attention is drawn to potentially harmful pigment degradation products.

An important group are also infectious complications. The risk of blood-borne infections (HBV, HCV, HIV) is associated primarily with obtaining tattoos in non-professional conditions and with non-compliance

with the principles of asepsis, which emphasises the key role of sanitary control, single-use equipment, and professional studios. Rarer complications have also been described, such as HPV and HSV infections and sporadic cases of infective endocarditis.

The available studies indicate that tattoo pigments do not remain solely at the site of administration but may migrate to regional lymph nodes together with metals and titanium dioxide particles. Data on their further systemic distribution are, however, limited, and the clinical significance of this phenomenon remains unclear. These observations have contributed to growing interest in the potential oncological risk associated with tattooing. The results of studies on the relationship between tattoos and lymphomas are inconclusive, and the reported cases of melanoma and other skin cancers developing within tattoos are most likely incidental in nature. The current state of knowledge does not allow confirmation of a cause-and-effect relationship between tattooing and the development of cancers, although the impeded diagnosis of pigmented lesions within tattooed skin constitutes a real clinical problem.

In summary, most complications associated with tattooing are local and usually mild, and the available data indicate that the vast majority of people with tattoos do not experience severe adverse effects. The most serious systemic complications occur rarely, while with regard to oncological risk the current state of knowledge does not allow confirmation of a cause-and-effect relationship between tattooing and the development of cancers. At the same time, significant gaps remain concerning the toxicology of ink components and the long-term effects of pigment migration. It should be emphasised that a considerable proportion of the available data comes from case reports and observational studies of variable quality, which limits the possibility of establishing causal relationships. This indicates the need for further epidemiological and mechanistic research, improvement of regulations concerning the composition of inks (including under the REACH Regulation), and the maintenance of high safety standards during tattooing and of diagnostic vigilance in the assessment of lesions developing within tattooed skin.

References

1. Kluger N. Epidemiology of Tattoos in Industrialized Countries. In: Serup J, Kluger N, Baumler W, eds. Current Problems in Dermatology. Vol 48. S. Karger AG; 2015:6-20. doi: https://doi.org/10.1159/000369175
2. Interactive H. One in Five U.S. Adults Now Has a Tattoo. Accessed July 1, 2026. https://www.prnewswire.com/news-releases/one-in-five-us-adults-now-has-a-tattoo-140123523.html
3. More Americans Have Tattoos Today than Seven Years Ago | Ipsos. August 29, 2019. Accessed July 1, 2026. https://www.ipsos.com/en-us/news-polls/more-americans-have-tattoos-today
4. Jaworska K, Fijalkowska M, Antoszewski B. Tattoos yesterday and today in the Polish population in the decade 2004-2014. *Health Psychology Report. 2018*;6(4):321-329. doi: https://doi.org/10.5114/hpr.2019.77175
5. Klügl I, Hiller KA, Landthaler M, Baumler W. Incidence of Health Problems Associated with Tattooed Skin: A Nation-Wide Survey in German-Speaking Countries. *Dermatology. 2010*;221(1):43-50. doi: https://doi.org/10.1159/000292627
6. Grant CA, Twigg PC, Baker R, Tobin DJ. Tattoo ink nanoparticles in skin tissue and fibroblasts. *Beilstein J Nanotechnol. 2015*;6:1183-1191. doi: https://doi.org/10.3762/bjnano.6.120
7. Schreiver I. Tattoo Pigments: Biodistribution and Toxicity of Corresponding Laser Induced Decomposition Products. Freie Universität Berlin. *Preprint posted online 2018*:151 Seiten. doi: https://doi.org/10.17169/REFUBIUM-1435
8. Giulbudagian M, Schreiver I, Singh AV, Laux P, Luch A. Safety of tattoos and permanent make-up: a regulatory view. *Arch Toxicol. 2020*;94(2):357-369. doi: https://doi.org/10.1007/s00204-020-02655-z
9. Laux P, Tralau T, Tentschert J, et al. *A medical-toxicological view of tattooing. The Lancet. 2016*;387(10016):395-402. doi: https://doi.org/10.1016/S0140-6736(15)60215-X
10. Serup J, Hutton Carlsen K, Sepehri M. Tattoo Complaints and Complications: Diagnosis and Clinical Spectrum. In: Serup J, Kluger N, Baumler W, eds. Current Problems in Dermatology. Vol 48. S. Karger AG; 2015:48-60. doi: https://doi.org/10.1159/000369645
11. Islam PS, Chang C, Selmi C, et al. Medical Complications of Tattoos: A Comprehensive Review. *Clinic Rev Allerg Immunol. 2016*;50(2):273-286. doi: https://doi.org/10.1007/s12016-016-8532-0
12. Weiß KT, Schreiver I, Siewert K, et al. Tattoos – more than just colored skin? Searching for tattoo allergens. *J Deutsche Derma Gesell. 2021*;19(5):657-669. doi: https://doi.org/10.1111/ddg.14436
13. Shao CG, Casterline BW, Martin KL. Tattoo-induced allergic contact dermatitis presents diagnostic challenge as a cellulitis mimic. *The American Journal of Emergency Medicine. 2024*;77:234.e1-234.e3. doi: https://doi.org/10.1016/j.ajem.2023.12.016
14. Tramontana M, Hansel K, Bianchi L, Sensini C, Malatesta N, Stingeni L. Advancing the understanding of allergic contact dermatitis: from pathophysiology to novel therapeutic approaches. *Front Med. 2023*;10:1184289. doi: https://doi.org/10.3389/fmed.2023.1184289

DOI: 10.12775/JEHS.2026.95.73995

15. Kaur RR, Kirby W, Maibach H. Cutaneous allergic reactions to tattoo ink. *J of Cosmetic Dermatology. 2009*;8(4):295-300. doi: https://doi.org/10.1111/j.1473-2165.2009.00469.x
16. Aberer W, Snauwaert JE, Render UM. Allergic Reaction to Pigments and Metals. In: Cuyper CD, Pérez-Cotapos S ML, eds. Dermatologic Complications with Body Art. Springer Berlin Heidelberg; 2009:61-89. doi: https://doi.org/10.1007/978-3-642-03292-9_6
17. Simunovic C, Shinohara MM. Complications of Decorative Tattoos: Recognition and Management. *Am J Clin Dermatol. 2014*;15(6):525-536. doi: https://doi.org/10.1007/s40257-014-0100-x
18. Pérez-Cotapos S. ML, De Cuyper C, Cossio L. Tattooing and Scarring: Technique and Complications. In: Cuyper CD, Pérez-Cotapos S ML, eds. Dermatologic Complications with Body Art. Springer Berlin Heidelberg; 2009:29-41. doi: https://doi.org/10.1007/978-3-642-03292-9_3
19. Bose R, Sibley C, Fahim S. Granulomatous and systemic inflammatory reactions from tattoo ink: Case report and concise review. *SAGE Open Medical Case Reports. 2020*;8:2050313X20936036. doi: https://doi.org/10.1177/2050313X20936036
20. Antonovich DD, Callen JP. *Development of Sarcoidosis in Cosmetic Tattoos. Arch Dermatol. 2005*;141(7). doi: https://doi.org/10.1001/archderm.141.7.869
21. Hutton Carlsen K, Serup J. Photosensitivity and photodynamic events in black, red and blue tattoos are common: A 'Beach Study.' Acad Dermatol Venereol. 2014;28(2):231-237. doi: https://doi.org/10.1111/jdv.12093
22. Bjornberg A. Reactions to Light in Yellow Tattoos From Cadmium Sulfide. *Arch Dermatol. 1963*;88(3):267. doi: https://doi.org/10.1001/archderm.1963.01590210025003
23. De Cuyper C, D'hoflander D. Materials Used in Body Art. In: Cuyper CD, Pérez-Cotapos S ML, eds. Dermatologic Complications with Body Art. Springer Berlin Heidelberg; 2009:13-28. doi: https://doi.org/10.1007/978-3-642-03292-9_2
24. Baumler W, Weiß KT. Laser assisted tattoo removal – state of the art and new developments. *Photochem Photobiol Sci. 2019*;18(2):349-358. doi: https://doi.org/10.1039/c8pp00416a
25. Ferguson JE, Andrew SM, Jones CJ, August PJ. The Q-switched neodymium:YAG laser and tattoos: a microscopic analysis of laser-tattoo interactions. *Br J Dermatol. 1997*;137(3):405-410.
26. Hauri U, Hohl C. Photostability and Breakdown Products of Pigments Currently Used in Tattoo Inks. In: Serup J, Kluger N, Baumler W, eds. Current Problems in Dermatology. Vol 48. S. Karger AG; 2015:CLXX-IV-CLXXIX. doi: https://doi.org/10.1159/000369225
27. Korabiusz K, Wawrykow A, Fabian-Danielewska A, et al. Laser removal of tattoo – a case report. Published online June 24, 2019. doi: https://doi.org/10.5281/ZENODO.3253463
28. Dieckmann R, Boone I, Brockmann SO, et al. The Risk of Bacterial Infection After Tattooing. Deutsches Ärzteblatt international. Published online October 7, 2016. doi: https://doi.org/10.3238/arztebl.2016.0665
29. Falsey RR, Kinzer MH, Hurst S, et al. Cutaneous Inoculation of Nontuberculous Mycobacteria During Professional Tattooing: A Case Series and Epidemiologic Study. *Clinical Infectious Diseases. 2013*;57(6):e143-e147. doi: https://doi.org/10.1093/cid/cit347
30. Lim SH, Lee S, Lee YB, et al. Increased prevalence of transfusion-transmitted diseases among people with tattoos: A systematic review and meta-analysis. Khan MR, ed. *PLoS ONE. 2022*;17(1):e0262990. doi: https://doi.org/10.1371/journal.pone.0262990
31. Tohme RA, Holmberg SD. Transmission of Hepatitis C Virus Infection Through Tattooing and Piercing: A Critical Review. *Clinical Infectious Diseases. 2012*;54(8):1167-1178. doi: https://doi.org/10.1093/cid/cir991
32. Foerster M, Zins M, Goldberg M, et al. Tattoo practices and risk of hepatitis B and hepatitis C infection in the French Constances study. *International Journal of Infectious Diseases. 2026*;163:108288. doi: https://doi.org/10.1016/j.ijid.2025.10828
33. Lavanych D. Worldwide epidemiology of HBV infection, disease burden, and vaccine prevention. *Journal of Clinical Virology. 2005*;34:S1-S3. doi: https://doi.org/10.1016/S1386-6532(05)00384-7
34. Cohen PR. Tattoo-Associated Viral Infections: A Review. *CCID. 2021*;Volume 14:1529-1540. doi: https://doi.org/10.2147/CCID.S284796
35. Armstrong ML, DeBoer S, Cetta F. Infective Endocarditis After Body Art: A Review of the Literature and Concerns. *Journal of Adolescent Health. 2008*;43(3):217-225. doi: https://doi.org/10.1016/j.jadohealth.2008.02.008
36. Ramey K, Ibrahim J, Brodell RT. Verruca localization predominately in black tattoo ink: a retrospective case series. *Acad Dermatol Venereol. 2016*;30(10). doi: https://doi.org/10.1111/jdv.13283
37. Kirchhof MG, Wong SM. Tattoos and human papilloma virus: A case report of tattoo-associated flat warts (verrucae planae). *SAGE Open Medical Case Reports. 2019*;7:2050313X19857416. doi: https://doi.org/10.1177/2050313X19857416
38. Ruocco V, Brunetti G, Puca R, Ruocco E. The immunocompromised district: a unifying concept for lymphoedematous, herpes-infected and otherwise damaged sites. *Acad Dermatol Venereol. 2009*;23(12):1364-1373. doi: https://doi.org/10.1111/j.1468-3083.2009.03345.x

39. Begolli Gerqari A, Ferizi M, Kotori M, et al. Activation of Herpes Simplex Infection after Tattoo. *Acta Dermatovenerol Croat. 2018*;26(1):75-76.
40. Anderson LL, Cardone JS, McCOLLOUGH ML, Grabski WJ. Tattoo Pigment Mimicking Metastatic Malignant Melanoma: Dermatologic Surgery. 1996;22(1):92-94. doi: https://doi.org/10.1111/j.1524-4725.1996.tb00578.x
41. Sepehri M, Sejersen T, Qvortrup K, Lerche CM, Serup J. Tattoo Pigments Are Observed in the Kupffer Cells of the Liver Indicating Blood-Borne Distribution of Tattoo Ink. *Dermatology. 2017*;233(1):86-93. doi: https://doi.org/10.1159/000468149
42. Nielsen C, Jerkeman M, Joud AS. Tattoos as a risk factor for malignant lymphoma: a population-based case-control study. eClinicalMedicine. 2024;72:102649. doi: https://doi.org/10.1016/j.eclinm.2024.102649
43. McConnell T, Xu J, Freeman J, Zak I, Frain J. Investigating the potential association between tattoos and lymphoma: an exploratory systematic review and meta-analysis. eClinicalMedicine. 2025;89:103563. doi: https://doi.org/10.1016/j.eclinm.2025.10356
44. Clemmensen SB, Mengel-From J, Kaprio J, Frederiksen H, Von Bornemann Hjelmborg J. Tattoo ink exposure is associated with lymphoma and skin cancers – a Danish study of twins. *BMC Public Health. 2025*;25(1):170. doi: https://doi.org/10.1186/s12889-025-21413-3
45. McCarty RD, Trabert B, Kriebel D, et al. Tattoos and Risk of Hematologic Cancer: A Population-Based Case-Control Study in Utah. *Cancer Medicine. 2024*;13(20):e70260. doi: https://doi.org/10.1002/cam4.7026
46. Kluger N, Koljonen V. Tattoos, inks, and cancer. *The Lancet Oncology. 2012*;13(4):e161-e168. doi: https://doi.org/10.1016/S1470-2045(11)70340-0
47. Brusasco M, Spagnolini S, Mazzoni L, Magi S, Scarcella G, Stanganelli I. Melanoma Arising in Tattoos: A Case Series and Scoping Review of the Literature. *Cancers. 2025*;17(5):767. doi: https://doi.org/10.3390/cancers17050767
48. Benandi K, Sieving D, Martin K, Wolf K. Malignant melanoma arising within tattoos as a risk factor for delayed diagnosis: a case report and systematic review. *DOJ. 2025*;31(3). doi: https://doi.org/10.5070/D331365358

Author's Contribution:
Conceptualization: AN, MF
Methodology: AB, RB
Investigation: AN, MF, MG
Writing – original draft preparation: AN, MF, AS, AB, RB, DS, LMS, MAB, MG
Writing – review and editing: AN, MF, AS, DS, MAB, MG
Visualization: AN, MF, AS
Supervision: AN
All authors have read and agreed with the published version of the manuscript.
Funding: This research received no external funding.
Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.
Data Availability Statement: Not applicable.
AI Disclosure: During the preparation of this work, the author(s) used Claude (Anthropic) for the purpose of language editing and translation of the manuscript into English. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.
Conflicts of Interest: The authors declare no conflict of interest.