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Assessing the Health Implications of UV/LED Nail Lamp Radiation Exposure During Manicure and Pedicure Procedures: A Scoping Review

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ABSTRACT

Skin malignancies associated with radiation exposure, notably malignant melanoma and keratinocyte carcinoma, are emerging as a significant global health challenge. While indoor tanning beds are associated with skin cancer risk, limited research exists on ultraviolet (UV)/light-emitting diode (LED) nail lamps used widely in manicures/pedicures. This scoping review aimed to synthesize evidence on the health effects of UV/LED nail lamp exposure during manicures/pedicures. A systematic search of PubMed, Scopus, and CINAHL identified 17 articles, including 12 studies and 5 case reports meeting eligibility criteria published in English from inception to January 2024. Several studies characterized emitted spectra and measured irradiances from commercial lamps, finding predominantly UVA emissions that complied with safety guidelines when correctly used. However, higher exposures exceeding safety limits were also observed. In vitro evidence demonstrated that UV nail lamps potentially induce DNA damage consistent with carcinogenesis. Case reports described squamous cell carcinoma and actinic keratosis restricted to the hands of patients with histories of extensive UV nail lamp exposure. While studies suggested that the cancer risks from typical use are acceptably low, there is room for improvement. Measurements have shown that the doses of UV emission vary across different lamps yet remain low. Surveys have revealed a need for more consumer awareness regarding these risks. Current evidence is insufficient to support the mandatory implementation of protective measures such as gloves or sunscreen during UV nail lamp exposure. More importantly, a direct causal link between UV nail lamps and carcinoma development has not been conclusively established.

1 | Introduction

The global nail salon industry continues to expand. The nail salon market was estimated to be worth 11 billion USD in 2022 [1], with Asia Pacific alone acquiring $3026.1 million in market share [2]. The market share is expected to increase to 19.4 billion USD by 2030, boasting a market growth of 7.9% compound annual growth rate [2]. This increase in growth is consumer-driven, with customers favoring gels and shellac in lieu of conventional nail polish. Nail salon services often involve the application of an acrylate gel polish followed by hardening and curing under an ultraviolet (UV) or light-emitting diode (LED) nail lamp [2]. UV lamps have been used in the nail industry for around 30 years [3]. These lamps help to cure the artificial nail coating [4] but emit ultraviolet radiation, primarily UVA (320–400 nm) and, to a lesser extent, UVB (280–315 nm).

LED lamps also emit UVA radiation, although generally less than traditional UV lamps. UVA penetrates deep into the skin, potentially promoting skin cancer or ocular damage. While gel nails promise extended wear and shine compared to conventional nail polish, the photocuring process has raised concerns regarding potential skin damage from repeated exposure to nail lamp radiation [5].

Skin cancers, specifically malignant melanoma and keratinocyte carcinoma, related to ultraviolet radiation, are becoming a growing concern for healthcare systems globally. UV radiation is linked with photoaging and skin cancer caused by DNA damage and oxidative stress [6, 7]. Basal cell carcinoma (BCC), squamous cell carcinoma (SCC), and malignant melanoma (MM) are associated with indoor tanning using UVA lamps like those used for nail curing [8, 9]. The escalating incidence of these cancers has been attributed to prolonged exposure to UV radiation emanating from indoor tanning practices [10]. However, few studies have specifically examined the carcinogenic risks of commercial UV nail lamps. With the rapid growth in the popularity of gel manicures, determining the potential long-term impact of nail lamp radiation exposure is an important public health concern.

Therefore, this scoping review aims to synthesize available evidence from human, animal, and in vitro studies published in peer-reviewed journals regarding the real and perceived health effects of exposure to radiation from UV/LED nail lamps used in manicure/pedicure procedures.

2 | Materials and Methods

We conducted a scoping review to chart the evidence and uncover the key ideas, theories, resources, and areas of uncertainty regarding both the actual and perceived effects of radiation exposure from UV/LED nail lamps employed during manicure/pedicure treatments.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews [11] was used and informed by the five key stages outlined by Arksey and O'Malley [12]: identification of the research question, identification of the relevant studies, selection of studies, charting of the data, and the collation, summary, and reporting of the results.

2.1 | Search Strategy

In January 2024, primary research published in English in peer-reviewed journals was systematically searched using electronic databases PubMed, Scopus, and CINAHL based on the inclusion and exclusion criteria shown in Table 1.

Medical subheadings (MeSH) and keywords were combined using the Boolean operators AND/OR to find relevant literature that reflected the aims of our review (see Table 2 for the PubMed search strategy example).

For consistency of the search strategy across the different databases, MeSH terms were adjusted to reflect the exact MeSH term/keywords. Articles were imported and managed in the bibliographic software.

TABLE 1 | Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Primary research published in English in peer-reviewed journals with no limits on the date of publication	Research published in languages other than English
Research letters/correspondence and case reports with primary data	Reviews, opinion pieces, discussion papers, editorials with no primary data, and theses
Research that focused on the real and perceived effects of exposure to radiation from UV/LED nail lamps used in manicure/pedicure procedures	Artificial tanning beds

After removing duplicate papers, the titles and abstracts of articles were screened for suitability for inclusion (DB, RK, MC, DL). Eleven articles were reviewed for eligibility for inclusion. A freehand search and review of the included study references identified six more articles (Figure 1). This resulted in 12 included studies and five case studies in this scoping review.

Since scoping reviews do not typically appraise study quality through validated tools, the authors did not conduct quality assessments on the included studies. Nevertheless, it is important to note that this does not imply a lack of rigor, as scoping reviews require researchers to evaluate methods and study findings during the analysis and presentation stages [14].

2.2 | Data Extraction and Synthesis

Data extracted from each study encompassed the author(s), year and country, the aims of the study/case, sample and study population, data collection and analysis, and the significant findings (see Table S1). Similarly, data extracted from each case report included the author(s), year and country, number of cases, age and gender, relevant history, anatomical position, device, exposure, and outcome (see Table S2).

Due to methodological heterogeneity, conducting a meta-analysis was not plausible. The data extracted from the included studies/case reports were reviewed, grouped into appropriate themes, and presented as a narrative summary. To ensure a rigorous, transparent process, all authors reviewed the analysis to attain consensus and ensure the review's original aim was achieved.

3 | Results

Seventy-two articles were retrieved from systematic searches across PubMed, Scopus, and CINAHL databases. After

TABLE 2 | Search strategy PubMed.

((Beauty Culture [mh] OR Cosmetic Techniques [mh] OR salon* [tiab]) AND (english[Filter])) AND (Feet [tiab] OR Foot [mh] OR Hand [mh] OR Nails [mh] AND (english[Filter])) AND (Carcinoma, Squamous Cell [mh] OR Skin Neoplasms [mh] OR Neoplasms, Radiation-Induced [mh] OR Ultraviolet Rays [mh] OR Photosensitizing Agents [mh] OR UV [tiab] OR DNA Damage [mh] AND (english[Filter]))

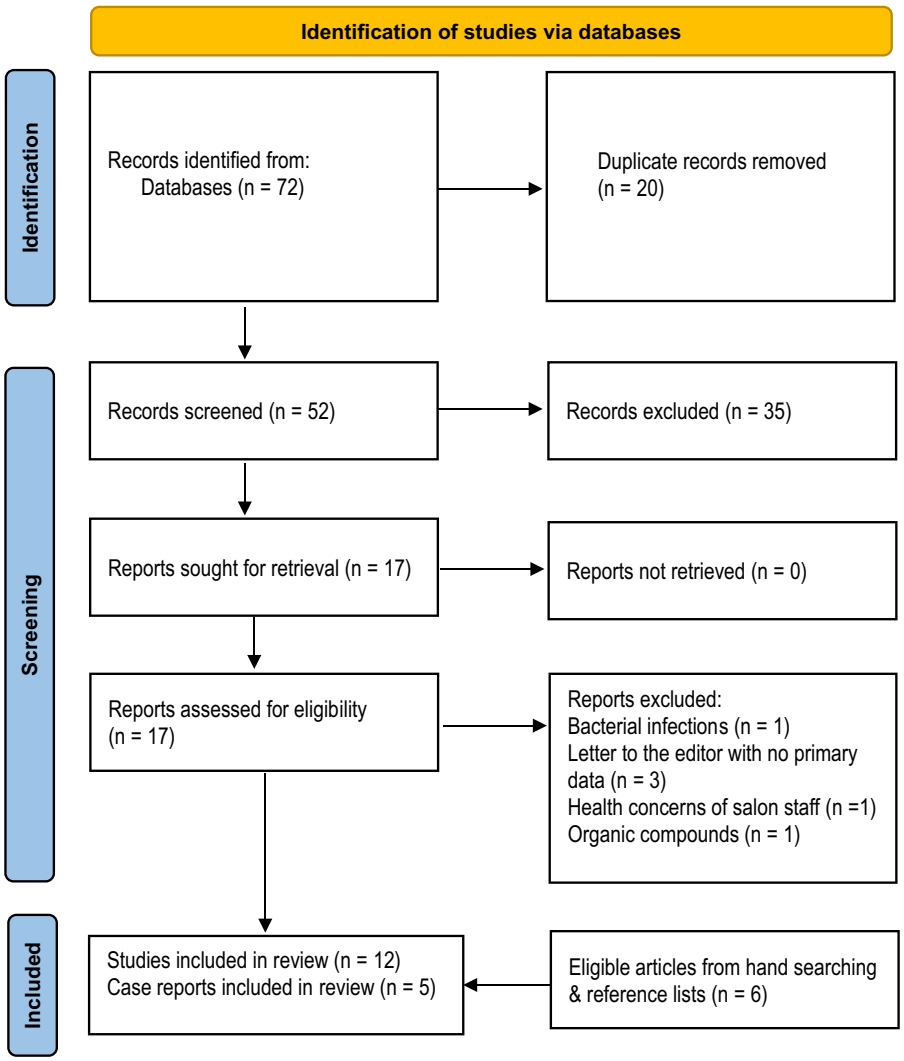

FIGURE 1 | Flow diagram of selection of studies process [13].

removing duplicates, 52 articles underwent title and abstract screening, identifying 17 potential publications assessed for eligibility. The full-text review found 11 articles that met the inclusion criteria. Additional hand-searching of reference lists identified six more relevant articles for inclusion [15–20]. Seventeen studies were included in the final synthesis as outlined in the PRISMA flow diagram showing study selection (see Figure 1).

3.1 | Study Characteristics

Most of the studies included were conducted in the USA [16, 18–28] ($n=12$), with others emanating from Australia [29] ($n=1$), the UK [3] ($n=1$), Ireland [30] ($n=1$), and Poland [15, 17] ($n=2$). Five of the included studies were case reports [19, 20, 26–28]. Six were theoretical/mathematical/experimental models [3, 21, 22, 24, 25, 29].

Two were in vitro studies [17, 18], one was a retrospective chart review [16], and three were surveys [15, 23, 30].

3.2 | Main Findings

Multiple studies characterized variable doses of UVA and UVB emissions from commonly used nail lamps across diverse manufacturers and models [21, 25]. At the recommended distances for consumer use, the measured exposure doses were generally below the risk thresholds for acute skin or ocular

damage as per safety guidelines [22]. However, the lamp's UV output was up to 4.2 times higher within the 355 to 385 nm range than the sun (at UV index = 6). Hence, a 10-minute exposure to a UV nail lamp is equivalent to the daylight exposure limit recommended for outdoor workers, potentially reaching skin cancer risk thresholds in under 10 minutes [21]. Using the current mathematical model, Diffey [3] estimates that the weekly usage of nail lamps would have to be monitored in tens/hundreds of thousands of women for many years to cause just one additional UVA-induced case of squamous cell carcinoma (SCC). Diffey [3] suggests that perhaps the current mathematical model should be revised. Despite anecdotal clinical evidence, multiple in vitro experiments confirmed DNA damage, including cytotoxicity, mutagenesis, and oxidative stress in diverse human and murine cell cultures subjected to nail lamp UV emissions [18].

A study by Lee et al. [29] assessed retinal damage caused by exposure to blue light (L_B) emitted from LED nail lamps. They compared nail salons' L_B effective radiance dose (D_B) to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guideline [31].

Although the L_B and D_B values were below ICNIRP limits for both the technicians and customers, the effects of long-term L_B exposure from nail lamps on retinal damage are yet to be determined.

However, an in vitro study conducted by Słabicka-Jakubczyk et al. [17] aimed to determine the viability of the human keratinocyte cell line after irradiation with a UV nail lamp. Treatment conditions included the application of sunscreen cream protection versus no protection, with untreated cells serving as controls. Notably, the researchers found that 4 minutes of UV exposure did not significantly impact cell viability compared to controls, mimicking real-world manicure duration. In contrast, 20 minutes significantly reduced cell viability by 35%. Clinical evidence suggests that long or multiple exposures to nail lamp UV/LED cause skin cancer predominantly on dorsal hands and feet [20, 26–28].

In a retrospective cohort study extending over 10 years, the effect of UV light exposure was compared in patients with basal/squamous cell carcinoma and those with non-malignant verruca [16]. UV light was not found to be a significant risk factor in the development of carcinomas of the hands [16]. Shipp et al. [25] suggested that it would necessitate a minimum range of 8 to 208 exposures to UVA nail lamps, equivalent to an energy density threshold of 60 J/cm^2, to potentially induce cutaneous damage related to keratinocyte carcinomas (KCs). This is supported by another study by Markova and Weinstock [24], which compared the irradiance of UV nail lamps to that of narrowband UVB (NB-UVB). They tested three types of UV nail lamps commonly used in salons: one with four 9-watt UV fluorescent bulbs, one with a single 9-watt UV fluorescent bulb, and one with six 1-watt LED lamps. The four and one 9-watt UV fluorescent bulb units emitted the highest irradiance. They concluded that one would need 13,000 sessions with the four or one 9-watt UV fluorescent bulb units to obtain additional cases of KC. This suggests that UV nail lamp exposure does not significantly increase the lifetime risk of skin cancers.

However, multiple case reports documented invasive and in situ SCCs at corresponding anatomical locations in patients with histories of routine long-term nail lamp use, occasionally necessitating extensive resections or digit amputations [20, 28]. Similarly, cases of actinic keratoses of the hand, thought to be caused by UV nail lamp exposure, were treated with cryotherapy [19]. Additionally, two patients diagnosed with systemic lupus erythematosus developed new skin lesions shortly after ceasing gel manicure regimens involving regular UV exposure over 4–12 years [27].

Survey findings highlighted critical knowledge gaps among female participants regarding skin cancer risks from nail lamp exposure [30]. While most participants had personal experience with UV nail devices through manicure treatments, less than a third accurately understood the potential carcinogenic hazards. Despite the availability of simple, inexpensive harm-reduction strategies, such as applying sunscreen prior to UV exposure, just 3% of participants took safety precautions [30]. Malinowska-Borowska and Buczkowska [15] found a similar educational gap among Polish UV nail lamp users. In view of this knowledge gap among consumers, an educational video intervention significantly enhanced nail technicians' ability to discern suspicious pigmented lesions in clients and improved confidence in recommending medical assessments concerning nail abnormalities [23].

4 | Discussion

The research assessing the health impacts of UV nail lamp exposure presents mixed findings. Several studies characterized the spectral outputs and measured irradiances, finding lamps emit predominantly UVA wavelengths [24, 25]. Importantly, the skin's response to UV light depends on several factors, including the dose delivered, the duration of the treatment, and the anatomical site of exposure. The hands exhibit unique properties based on skin thickness profiles, structural components like collagen and elastin fibers, and preconditioning to sun exposure, making the dorsal surface more resistant to UV damage than other body areas [32]. When used at the recommended distances, nail lamp irradiances comply with safety guidelines [22, 29]. Yet, Curtis et al. [21] reported certain lamps can emit levels of radiation that surpass safety thresholds for outdoor workers in under 10 minutes, delivering an energy dose to a person's hands equivalent to the entire day's recommended limit for outdoor work.

However, these findings require careful interpretation, as highlighted by Dowdy and Sayre [33]. While Curtis et al. [21] referenced ANSI/IESNA product emission standards for risk classification [34], were designed for product certification using acute response UV spectral weighting functions rather than evaluating cumulative skin exposure safety or non-melanoma skin cancer (NMSC) risks. Both Curtis et al. [21] and Markova and Weinstock [24] studies had methodological limitations, with Markova and Weinstock [24] conducting a cursory evaluation of two UV nail lamp units, while Curtis et al. [21] reached conclusions regarding "high-intensity exposure" based on uncommon measurements. Both studies used single fixed-grating diode array spectrometers, which lack adequate

single-measurement dynamic range and standard stray light rejection capabilities—technical specifications explicitly required by international testing standards for photobiological UV risk evaluation [35]. More rigorous analyses by Diffey [3] and Dowdy and Sayre [22] using appropriate instrumentation—specifically UV–visible double grating scanning spectroradiometers with integrating spheres calibrated to National Institute of Standards and Technology traceable standards—have demonstrated that UV nail lamps present only moderate risks with 30 to 130 min of permissible daily occupational exposure. Furthermore, calculations using the International Illumination Commission non-melanoma skin cancer spectral weighting [33, 36] showed that NMSC risk from nail lamps was 11 to 46 times less than overhead sunlight and 3 to 12 times less than mid-angle sunlight for equivalent exposure duration. It is important to note that product safety standards do not specifically incorporate NMSC risk assessment guidance. The accumulated estimate of habitual nail lamp exposure amounts to only 1.1 to 1.5 MED/year, as reported by Curtis et al. [21] contradicts their conclusions about safety concerns. As UVA radiation is an established carcinogen [37], a related study examining cadaveric fingernails found that while the nail plate fully blocked UVB wavelengths (registering 0 mW/cm2 on radiometer readings), it permitted 0.6%–2.4% penetration of UVA rays to reach the nail bed [38]. Consequently, the nail affords a degree of shielding against certain wavelengths but allows substantial transmission of UVA to underlying tissues. However, the precise nature of the DNA damage caused by UVA radiation is not yet fully understood [39, 40].

Recent in vitro experimental evidence suggests that UV nail lamps induce DNA damage. Zhivagui et al. [18] observed elevated DNA damage markers, including cytotoxicity and mutagenesis, in irradiated keratinocytes, fibroblasts, and stem cells. While Słabicka-Jakubczyk et al. [17] found significantly reduced viability of human keratinocyte cells following an extended UV light exposure. However, the keratinocyte cell culture experiments in Słabicka-Jakubczyk et al. study [17] represent a simplified model that does not account for the natural UV attenuation through the skin's upper layers. As Finlayson et al. [41] demonstrated, UV radiation is significantly attenuated as it penetrates the stratum corneum and epidermal layers before reaching keratinocytes in human skin. Therefore, the UV exposure levels experienced by keratinocytes in Słabicka-Jakubczyk et al. [17] experiments likely overestimate the actual exposure in intact human skin. This suggests that their findings regarding cellular damage may represent a 'worst-case scenario' compared to real-world conditions where the skin's natural protective barriers would reduce UV penetration to deeper keratinocytes.

These in vitro studies arose following a comprehensive review by Suzuki and Kamiya [42], which established a correlation between the irradiation and the accumulation of 8-oxo-dG, indicating oxidative base changes that last up to 24 h after exposure—in addition to the formation of reactive oxygen species-clustered DNA lesions repaired as double-strand breaks, a potential mutagenic outcome mediated by UVA exposure [43]. Exposure also enhanced mitochondrial superoxide generation and disrupted membrane potential, implicating mitochondrial dysfunction [18].

However, the clinical evidence regarding the risks of carcinogenesis from UV nail lamps is conflicting. Multiple case reports have described SCC and actinic keratoses restricted to the dorsal hands in patients with decades-long UV nail lamp use histories [19, 20, 26, 28]. Moreover, autoimmune conditions affecting the skin, primarily cutaneous lupus erythematosus, could potentially be exacerbated after UV light irradiation [27, 44]. In contrast, a research-based review by Breuckmann et al. [45] demonstrated that UVA phototherapy has an acceptable risk-to-benefit ratio despite the potential for causing malignancies, deteriorating cutaneous conditions, and accelerating photoaging. This is particularly true for conditions such as lupus erythematosus, localized scleroderma, systemic sclerosis, and extragenital lichen sclerosus.

Markova and Weinstock [24] tested several models of nail lamps and concluded that one would need 13,000 sessions of UV exposure in order to obtain one additional case of KC, that is, SCC/BCC. Four years later, Schoon et al. [46] showed similar results with negligible risk of developing KC testing two commonly used nail lamps. The UVA radiation from salon appointments is equivalent to a few extra minutes of daily sunlight, while UVB exposure corresponds to a few seconds of additional sunlight per day. Furthermore, mathematical modeling developed by Diffey [3] has estimated very low cancer risks from typical usage. According to these findings, it is safe to assume that the risk of developing KC due to nail UV lamps is negligible and will probably be accepted by most women undergoing aesthetic nail procedures in these salons. Survey studies among nail salon visitors have revealed a lack of consumer awareness about the potential links between UV nail lamps and cancer risk [15, 30]. This finding supports the need for educational initiatives aimed at risk mitigation and even documented consumer consent prior to treatment.

Interestingly, a retrospective study by Scott Henning et al. [16] found no association between nail UV exposure and finger NMSC. However, Lazovich et al. [47] demonstrated a significant effect of indoor tanning on SCC incidents, with weaker associations observed for BCC, thereby supporting the notion that UV lamps may enhance carcinogenic risks. While these findings allude to possible health impacts, direct comparison between studies should be interpreted cautiously, as indoor tanning devices and nail lamps differ substantially regarding irradiation intensity, total radiation output, exposure duration, and anatomical site of exposure. Hence, the quantified carcinogenic risk of UV emitted by nail lamps remains negligible [16, 17, 21, 24]. Shipp et al. [25] conducted a broader investigation, assessing 17 distinct light sources from 16 nail salons across various geographical locations within the United States. Through the measurement of UVA and UVB radiation, the study revealed notable inter-device variability with respect to UVA emissive profiles among the examined sources. The large variance may be reasonably attributed to device type and configuration differences, such as bulb wattage and quantity, as seen in the reports of Markova and Weinstock [24] and Lee et al. [29].

Although the cutaneous carcinogenic risk appears negligible, multiple papers suggest it would be wise to recommend risk reduction strategies such as gloves [15, 25] and broad-spectrum

sunscreen protection (SPF > 30) [15, 17, 21, 25, 30] prior to nail procedures to limit risks of photocarcinogenesis and photoaging. As this technology continues to evolve, evaluating its potential health impacts is crucial.

This study is not without limitations. Large epidemiological studies are required to better evaluate the risk of cancer due to UV nail-lamp exposure in different ethnic and genetically diverse populations. This review only included studies published in English, so other relevant non-English articles may have been missed. In addition, the included studies had heterogeneous designs, study cohorts, exposure levels, and assessed outcomes, limiting direct comparisons between studies. Given the variation in practices between nail salons, there are notable differences in UV lamp models, output intensities, and exposure times between studies, which also challenge comparisons. Additionally, causality cannot be definitively determined from the available evidence, which is limited by a lack of large prospective cohort studies and reliance on case reports and studies with small sample sizes.

A significant methodological challenge is the inability to separate UV exposure from manicure/pedicure procedures from ambient UV exposure of the hands, particularly given that epidemiological databases typically do not provide sufficient anatomical detail about the precise location of SCCs and AKs on the dorsum of the hands. Finally, while ICNIRP guidelines [31] provide valuable exposure limits for electromagnetic radiation, their direct application to quantitative cancer risk assessment requires careful consideration of several factors. The ICNIRP guidelines acknowledge that while a single exposure limit can be applied for eye protection, skin exposure limits should be considered "advisory" due to the wide variation in susceptibility across different skin phototypes. Additionally, the UV spectral weighting function used in ICNIRP guidelines differs from that used for non-melanoma skin cancer (NMSC) assessment [36]. These limitations suggest that ICNIRP-based exposure assessments should be interpreted with appropriate caution when evaluating potential carcinogenic risks from UV nail lamp exposure.

5 | Conclusion

Evidence regarding UV/LED nail lamp carcinogenicity remains inconclusive based on the available data. While some in vitro experimental findings and case reports have indicated potential mutagenesis from UV/LED lamp exposure, current evidence is insufficient to support the mandatory implementation of protective measures such as gloves or sunscreen in salon settings. Several risk assessments suggest UV exposure from nail lamps presents minimal risk when used as intended in typical salon conditions. More importantly, a direct causal link between UV nail lamps and carcinoma development has not been conclusively established, with existing studies showing significant methodological limitations and contradictory findings. Continuous re-evaluation of health impacts remains prudent, given the widespread use of UV/LED nail lamps and technological advances. Further in vivo research could help elucidate long-term outcomes to guide future risk management. Enhancing consumer education may help facilitate informed decision-making regarding cosmetic UV/LED treatments. While the scientific data does not demonstrate a clear need for protective interventions, obtaining informed consent could be considered to support client autonomy. Evidence-based guidelines should continue to inform industry practices as new research emerges.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.