

Rethinking Infection Control in the Professional Nail Industry: A Biomechanical Engineering Approach and Medical Safety Standards

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Abstract: *Within the scientific and research context, an objective need is recorded for a radical renewal of infection-control protocols in the nail-service industry. The rapid expansion of the global market, valued in 2024 at 24.56 billion United States dollars with an expected increase to 36.27 billion by 2032, is accompanied by a persistent mismatch between dominant aesthetic practices and the requirements of biological and chemical safety. The relevance of the problem is intensified by data from 2024–2025 indicating an increased probability of reproductive dysfunctions, chronic respiratory disorders, and epidemiologically significant transmission of bloodborne infections within the professional environment. As a priority, systemic integration of engineering protective measures is considered, including local aerosol and dust capture systems, as well as the introduction of biomechanically correct methods for processing the nail plate, including the SlimEdge 45° technique described in the work *Secrets of the Perfect Design*. The rationale shifts from the concept of visually sufficient disinfection toward regimes comparable to medical standards of sterilization, taking into account critical points of contamination of instruments and surfaces. Additionally, the regulatory factor is analyzed in the form of the European Union 2025 ban on the use of photoinitiators (TPO), and a model of engineering design for a safe workspace is formed, oriented toward minimizing aerogenic and contact risks, as well as toward reducing cumulative chemical load under conditions of everyday practice.*

Keywords: infection control, nail-plate biomechanics, SlimEdge 45°, engineering design of ventilation, occupational diseases, Nailypmia, biological safety, volatile organic compounds.

1. Introduction

The contemporary nail industry exhibits a pronounced contradiction: against the backdrop of annual growth of approximately 6% and a shift toward the premium segment, whose share by 2025 reaches 60% of the market, the professional environment retains the characteristics of a high-risk zone for health [1]. For a long time, infection control in this field was interpreted primarily as a subsidiary component of sanitary discipline; however, the totality of current data requires transferring the analytical frame into the domain of evidence-based medicine and industrial engineering. The high resilience of the global market to macroeconomic fluctuations is confirmed by rising demand for complex modeling methods and by the diffusion of gel technologies [1, 2]. At the same time, the expansion of the procedural spectrum is predictably accompanied by increased exposure of personnel and clients to chemical toxicants and to biological agents capable of generating infectious risks.

Evidence from 2024 indicates the inadequacy of existing regulatory mechanisms for effective worker protection. In New York, a region with one of the most stringent regulatory systems in this sphere, 17% of specialists report reproductive health disruptions, which substantially exceeds the national average (11%) [3, 4]. This disproportion reflects the limitations of traditionally applied measures, including the use of non-specialized masks and household air-conditioning systems, which do not form a reliable barrier against fine aerosol and volatile organic compounds (VOCs) arising during filing and polymerization of materials.

The gap between medical requirements and the actual practices of the aesthetic-services industry is most clearly

manifested in standards for instrument sterilization and in approaches to indoor air quality. In clinical protocols, unconditional sterility is treated as a mandatory condition for any instrument capable of contacting damaged skin, whereas in nail services the prevalence of low-level disinfection persists even for items associated with bleeding risk (nippers, pushers) [5, 6]. In parallel, engineering solutions for organizing workstations are often implemented without consideration of the aerodynamic regularities of aerosol transport, which promotes recirculation of vapors and particles within the specialist's breathing zone and sustains chronic inhalation load [7].

The aim of the study is to demonstrate that the transition to an acceptable level of occupational safety is possible only through the simultaneous implementation of a biomechanically correct filing technique (using SlimEdge 45° as an example), clinically oriented pathogen control, and highly efficient aspiration systems that ensure local capture of contaminants at the source. This linkage is regarded as the minimally sufficient basis for bringing sectoral practices into alignment with safety requirements as updated for 2025.

Scientific novelty is defined by the fact that, within the present work, an integrated medico-engineering framework is proposed for nail services for the first time. This framework connects critical points of contamination and levels of instrument processing according to the logic of clinical IPC; the effectiveness of local exhaust and source capture; and the biomechanics of the nail plate as a factor of microtraumatization and subsequent infectious risk.

The authorial hypothesis rests on the assumption that sustained reduction of infectious and toxicological risks in nail practice is achievable only through a concurrent

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transition to clinically equivalent sterilization, mandatory engineering control of the air environment, and a decrease in microdamage via a biomechanically rationalized filing technique, whereas isolated measures (disinfection alone or ventilation alone) yield only a partial effect.

2. Materials and Methods

Within the study, a multifactor analysis of empirical and regulatory materials was conducted, ensuring comparability of conclusions along the lines of occupational morbidity-engineering protection — technological technique — regulatory environment- microbiological risks. The epidemiological block was formed on the basis of reports by the New York Healthy Nail Salons Coalition from April 2024, including the results of a survey of 312 specialists, as well as a systematic review of occupational risks encompassing publications and reports through November 2025 [4]. This body of evidence made it possible to assess the structure of complaints, the frequency of adverse outcomes, and likely determinants of exposure under real working conditions.

The engineering and technical component is represented by an audit of the effectiveness of local contamination-capture systems at the workstation, including Source Capture and local exhaust ventilation (LEV), drawing on NIOSH laboratory studies and field testing in New York salons conducted in 2025 [7]. This design enabled comparison of reductions in concentrations of aerosol fractions and volatile organic compounds with installation parameters, workspace configuration, and operating regimes.

The biomechanical direction included modeling the behavior of the nail plate as a composite keratin structure using principles of strength of materials and solid mechanics. This framework was used for an analytical interpretation of the SlimEdge 45° technique described in the methodological manual *Secrets of the Perfect Design*, with emphasis on stress distribution, the risk of microcrack formation, and the predictability of filing geometry under different vectors of applied force [11]. This made it possible to link the technological method not only to an aesthetic outcome but also to potential biomechanical preconditions for traumatization and subsequent contamination.

A comparative analysis of regulatory systems was performed by juxtaposing updated European Union requirements (Reg. 2024/197), which provide for a ban on TPO and DMTA, with existing OSHA and CDC approaches that define the framework for managing occupational risks and sanitary control [13]. Consideration of the norms was carried out with attention to differences in regulatory logic: from product-oriented restrictions and chemical safety to procedural standards and exposure-management practices.

The microbiological review was aimed at assessing transmission pathways for bloodborne pathogens (HBV, HCV, HIV) and the characteristics of bacterial burden under different types of nail status, including the presence of gel coating and the natural nail plate [15]. The analysis included mechanisms of contamination of instruments and surfaces, factors governing microorganism survival within the microenvironment of the coating, and the conditions under

which microdamage and contact with biological fluids increase the probability of infection.

3. Results and Discussion

A critical reappraisal of infection control must be grounded in a verified understanding of the true scale of health threats. The professional environment of nail services is shaped by combined exposure to chemical and biological factors, among which volatile organic compounds, acrylate monomers and polymers, and agents of microbial origin are of key importance, potentially persisting on instruments, surfaces, and in the aerosol phase. Chronic exposure to VOCs and acrylates creates conditions for systemic toxicological burden and sensitization, whereas the presence of biological contaminants sustains the risk of contact transmission and indirect infection in the setting of microdamage to the skin and periungual tissues [16, 18].

Survey results for 2024 reflect an unfavorable dynamic affecting reproductive health and the course of pregnancy, indicating the insufficiency of existing preventive practices and the need to conceptualize the workplace as a source of complex exposure. In such a context, infection control ceases to be a narrow issue of sanitary processing and instead requires integration of a clinical-epidemiological approach with engineering solutions for managing aerosol emissions and chemical vapors, including local capture of contaminants at the source and standardization of procedures that minimize biological contamination.

Table 1 presents a comparison of health risks among nail service professionals and the United States population.

Table 1: Comparison of health risks among nail service professionals and the United States population (compiled by the author based on [4])

Health outcome category	Nail service practitioners (%)	United States general population (%)	Relative risk
Reproductive health disorders	17%	11%	1.55
Pregnancy-related complications	18%	8%	2.25
Birth of children with congenital anomalies	7%	2-3%	2.33
Chronic cough / ocular irritation	67-70%	<15%	>4.0

The high frequency of adverse outcomes among workers in the nail industry is largely explained by the cumulative nature of combined exposure, which includes components of the so-called toxic trio consisting of dibutyl phthalate, toluene, and formaldehyde, as well as methyl methacrylate (MMA). Even in the presence of official prohibitions on the use of MMA in the United States and a number of other jurisdictions, its detection in salon air samples in 2025 indicates persistent gaps in market-control systems and insufficient effectiveness of existing oversight mechanisms [9]. The chemical hazard in this context is not isolated: toxicological burden is superimposed on biological contamination, forming a synergistic risk profile in which the irritant and sensitizing effects of chemical agents are combined with the possibility of pathogen transfer via contact surfaces and microaerosols.

Microbiological data from 2024 demonstrate that bacterial colonization of the nail plate tends to increase over time regardless of the selected coating type, whether natural plate, lacquer, or gel systems [17, 18]. At the same time, gel polish is characterized by lower susceptibility to the effects of standard hygienic hand processing compared with natural nails; as a consequence, the presence of artificial coatings among personnel may increase the probability of mechanical transfer of microorganisms in clinical and domestic contexts [17, 19]. This conclusion is fundamentally important for infection control because it shifts the emphasis from exclusively client-oriented safety to an assessment of the worker's role as a potential link in the chain of transmission.

Reduction of inhalation exposure and of concentrations of aerosol fractions in the work zone in 2024–2025 is increasingly associated with a revision of the engineering logic of ventilation: general exhaust ventilation (GEV) yields priority to systems that capture contamination directly at the source (Source Capture Systems). It has been shown that the simplest measures, including airing through windows and doors, under idealized conditions are capable of reducing concentrations of volatile organic compounds by 82.2%; however, such a strategy is inherently unstable because it depends on weather factors and the architectural characteristics of the premises, and therefore does not ensure a reproducible level of protection [7, 20]. Against this background, the requirements of the International Mechanical Code (IMC 2024) are being updated, setting engineering parameters for workstations: minimum exhaust capacity is regulated at 50 cubic feet per minute for each service point, and the air intake must be located within 12 inches (30 cm) of the zone of application of the chemical agent, both horizontally and vertically [8]. As a technological basis for filtration, the use of eHEPA® is considered, combining electrostatic precipitation and HEPA filtration, which is aimed at capturing ultrafine dust particles and aerosolized acrylate vapors [21]. Experimental data from NIOSH confirm that correctly calculated and properly installed downdraft tables are capable of reducing occupational exposure to chemical agents by at least 50–60% [10]. However, even in the presence of technically substantiated solutions, a systemic implementation deficit persists: 71% of salons continue to operate with inadequate ventilation that fails to meet even baseline requirements for fresh-air supply, thereby sustaining chronic aerogenic burden in the breathing zone of personnel [9, 22].

The effectiveness of infection control is determined not only by the level of contaminant removal from the air, but also by the degree to which natural barrier structures are preserved. The nail plate is a functionally significant composite keratin system comprising approximately 80–90 layers of cornified keratinocytes, and its biomechanical stability is directly associated with resistance to microdamage capable of forming portals of entry for infection [12]. In this context, the SlimEdge 45° technique described in *Secrets of the Perfect Design* is interpreted as a technologically meaningful shift toward biomechanically rationalized filing, in which the geometry of movement and the position of the abrasive are considered through the lens of stress distribution within the material [11]. Holding the file at an angle of 45° to the lateral wall makes it possible to form a stiffness edge without critical

thinning of the natural plate, thereby reducing the probability of structural destabilization [11, 25]. A substantial component is accounting for the orientation of keratin fibers in the intermediate layer, which are arranged transversely, that is, parallel to the free edge; filing in a single direction reduces the risk of microcrack formation, whereas reciprocating sawing movements promote their deepening and the creation of microreservoirs potentially suitable for the persistence of fungal and bacterial flora [12, 24]. When forming lateral parallels, application of the 45° angle contributes to a more optimal distribution of mechanical stress in the stress-point zone, which is associated with a reduced frequency of material detachments (lifting); detachments are regarded as one of the key factors creating a substrate for the development of *Pseudomonas* beneath an artificial coating. Additional significance is carried by the acid–base profile: the pH of the nail plate is around 5.0, and its elevation, for example through frequent handwashing or the use of aggressive primers (to pH 5.3 and higher), weakens the acid mantle and potentially increases vulnerability to mycoses [23]. Within this logic, SlimEdge 45° is interpreted as an approach that minimizes the area of aggressive mechanical-chemical impact and supports the architectural integrity of the dorsal layer, which is functionally linked to preservation of the plate's barrier role [12, 26].

Against the background of the factors listed above, the most acute issue remains the mismatch between instrument-processing practices and the level accepted in medicine. Expert assessments from 2024 emphasize that hepatitis B virus (HBV) possesses substantially higher infectivity than human immunodeficiency virus and hepatitis C virus and is capable of persisting on instruments for a prolonged period; under insufficient sterilization discipline, isolated protocol breaches are thereby transferred into the category of epidemiologically significant risks [15] (see Table 2).

Table 2: Instrument processing in nail services according to the Spaulding classification: requirements and actual practice (compiled by the author based on [5, 27, 28]).

Spaulding risk level	Instrument type in nail service	Required level of reprocessing	Reality in most salons
Critical (contact with blood / damaged skin)	Nail nippers, cuticle pushers, rotary bits	Sterilization (Class B autoclave)	Disinfection with chemical solutions / dry heat sterilizer
Semi-critical (contact with intact mucosa / skin)	Soaking bowls	High-level disinfection	Rinsing with water / surfactants
Non-critical	Lamps, hand rests	Low-level disinfection	Absent

Key deficiencies in current infection-control practices in nail services include reliance on ultraviolet devices marketed as sterilizers, although by functional purpose they are storage boxes and do not ensure microorganism inactivation [29, 30]. In conditions where procedures are often associated with microdamage to the skin and contact with biological substrates, a transition to protocols comparable to dental standards becomes justified: abrasive materials must be treated as single-use, and metal instruments must be treated as critical objects within the sterilization cycle, with mandatory autoclaving in individual kraft pouches and the use

of control indicators confirming correct processing [15]. Such standardization moves safety from the category of recommendations into the domain of reproducible procedures with a verifiable outcome.

A significant factor that accelerated the reassessment of chemical safety was the regulatory shift of 2025: starting September 1, 2025, EU Regulation 2024/197 enters into force, altering the permissible composition of photopolymerizable systems [13]. The ban on the photoinitiator trimethylbenzoyl diphenylphosphine oxide (TPO) is associated with its classification as CMR 1B, that is, substances with proven reproductive toxicity for humans [13]. This reveals a systemic vulnerability of the market in which some products promoted as safe in fact contained components potentially affecting fertility and embryofetal development. In this context, restructuring of control implies excluding materials containing TPO and DMTA, used as an adhesion conditioner [14]. At the same time, a transition to alternative photoinitiators is required, which inevitably entails the need to calibrate lamp power and spectral compatibility: if parameters do not match, the risk increases both for chemical burn and for incomplete polymerization with persistence of reactive residues [13]. Separate attention should be given to labeling audits, because research data indicate that declared 10-free formats often create a false impression that toxicologically significant components are absent, while masking the presence of other potentially hazardous acrylates [31-33].

Regulatory and technological transformation clearly correlates with professional practices demonstrated at the international Naillympia 2024–2025 competitions, where the aesthetic result is formally linked to hygiene and product control. Judging criteria in the Workmanship and Product Control sections include assessment of workstation cleanliness, absence of dust, and the condition of the model's cuticle, and any skin damage (abrasion) leads to an immediate reduction in points, underscoring the priority of biological safety over decorative effect [34, 35]. This logic of discipline, implemented at championships through mandatory processing of hands and instruments under the threat of disqualification, should methodologically be transferred into routine salon practice as an integral part of the protocol rather than as an optional measure [24].

For systematic risk reduction, adaptation of the medical Hierarchy of Controls to nail services is proposed, because it establishes a sequence of interventions from the most effective to the auxiliary [36, 37]. At the elimination level, this entails avoiding toxic methacrylates and a transition to technologies that do not require aggressive filing of the natural nail, as well as the use of single-use materials in situations where guaranteed sterilization is fundamentally unattainable. The substitution level provides for withdrawing formulations with TPO in favor of alternative formulas by September 2025 and using 3-free or 7-free solutions on the condition that their composition is confirmed by laboratory analysis rather than only by marketing declaration [13]. Engineering control is interpreted as mandatory installation of source capture systems with capacity greater than 50 cfm and the introduction of Industry 4.0 approaches for automated monitoring of salon air quality [21]. Administrative measures

include standardized training in the biomechanically correct SlimEdge 45° filing technique and implementation of pre-procedure screening protocols with identification of signs of mycotic involvement and breaches of skin integrity before the service [11]. The final level is represented by personal protective equipment, where the use of nitrile gloves is considered rational as a barrier to acrylates and the use of N95-class respirators for reducing inhalation load from fine dust [9].

4. Conclusion

Infection control in the professional nail industry loses viability when reduced to formal compliance with sanitary requirements developed for a different technological reality. Materials from 2024–2025 show that the sector operates under a complex risk constellation that requires methodological convergence with evidence-based medicine and engineering disciplines. Elevated prevalence of reproductive and respiratory disorders among specialists, reaching 17–18%, correlates with chronic inhalation burden driven by inadequate organization of air exchange and by the use of toxicologically significant compounds, including MMA and TPO. The solution vector shifts toward engineering design of workplaces, where the priority becomes capturing contaminants directly at the source; the application of such systems is associated with a reduction in exposure to volatile organic compounds by 70% and more, which moves prevention from a declarative plane into a measurable and reproducible protective framework.

In parallel, technological safety cannot be ensured exclusively through ventilation measures, because infectious risk increases when tissue integrity is compromised and when microspaces form that are suitable for persistence of microflora. Biomechanically oriented processing of the nail plate, implemented in the SlimEdge 45° technique, is regarded as a tool for reducing traumatization and preventing the formation of niches capable of sustaining the development of pathogenic associations. The deficit of alignment between medical standards and beauty-industry practices must be eliminated through a transition to demonstrable instrument sterilization regimes, including autoclaving, and through ensured traceability and transparency of the chemical composition of materials used, which has direct significance for managing reproductive and toxicological risks.

A forward-looking trajectory for the sector is linked to the formation of smart salons on Industry 4.0 principles, where safety parameters are controlled by technical means, and professional training includes understanding of contaminant aerodynamics, the physics of polymerization, and biological mechanisms of pathogen transmission. As a result, nail services must evolve from a predominantly artistic practice into a high-technology discipline in which preserving the health of the specialist and the client becomes the baseline quality criterion.

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