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Chemical Mechanisms of Allergic Reactions to Eyelash Extension Materials and Eyebrow Dyes, Methods for the Safe Use of Products in Professional Practice

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Abstract

The work is devoted to a multi-level analysis of chemical-immunological processes that determine the onset of allergic reactions to materials for eyelash extension and eyebrow coloring, with emphasis on products circulating on the US market. The aim of the study is to consolidate information on the ingredient composition of commercial products, the mechanisms of pathogenesis of allergic contact dermatitis (ACD), and to formulate scientifically grounded protocols for safe use by beauty-industry professionals. The methodological basis includes a systematic analysis of publications from Scopus, PubMed, and Web of Science, as well as a content evaluation of regulatory and technical documentation (MSDS) of leading American brands and entries in the FDA MAUDE database. The data obtained indicate that the dominant allergens are ethyl 2-cyanoacrylate in adhesive compositions and p-phenylenediamine (PPD) in coloring preparations; both act as haptens and initiate a cell-mediated type IV hypersensitivity reaction. The article presents a detailed scheme of ACD pathogenesis, a statistical assessment of the frequency of adverse events, and a comparative analysis of the compositions of the most popular products. A conclusion is formulated on the need to increase practitioners' awareness of sensitization mechanisms, the limitations of patch testing, and the importance of thorough medical history taking, including information on previous surgical interventions. The developed protocols for safe use, including algorithms for managing acute reactions, are aimed at reducing health risks for clients and strengthening safety standards in the industry. The material is addressed to practicing beauty specialists, dermatologists, allergist-immunologists, and researchers in cosmetic chemistry.

Keywords: *Eyelash Extension, Eyebrow Coloring, Allergic Contact Dermatitis, Cyanoacrylate, P-Phenylenediamine, Hapten, Type IV Hypersensitivity, Cosmetics Safety, Safety Protocols, Occupational Risks.*

INTRODUCTION

The industry of cosmetic procedures for eyelash extensions and brow architecture is demonstrating accelerated expansion, fueled by the effects of social platforms and a growing consumer demand for appearance optimization. Estimates indicate that the market size for eyelash extension services in the United States amounted to 245,8 million USD in 2023 and is projected to reach 424,8 million USD by 2032, corresponding to a compound annual growth rate of 6,6% [1]. At the global level, the dynamics are even more pronounced: an increase from 1,82 billion USD in 2024 to 3,12 billion USD by 2032 is expected (CAGR 6,95%) [2]. At the same time, this rapid growth is accompanied by a parallel increase in the incidence of adverse events and side reactions. Publications indicate a high prevalence of complications: more than half of clients following eyelash extensions report symptoms, including pruritus, conjunctival hyperemia, and pain in the periorbital region [3, 4]. In a broader perspective, allergic contact dermatitis—a key type of response to a range of cosmetic ingredients—is recognized as one of the most common forms of human immunotoxicity and, according to various data, affects up to 20% of the population [5, 6].

Despite a substantial body of clinical descriptions of adverse effects, a fundamental methodological gap persists in the scientific field: there is no comprehensive review that systematically juxtaposes the chemical structure of specific materials widely used on the American market (in particular, adhesives and dyes) with the subtle immunological cascades underlying hypersensitivity reactions. Practical regulations for eyelash extension and brow design technicians remain largely empirical, fragmented, and rarely grounded in the fundamental tenets of toxicology and immunology of key formulation components.

The aim of the study is to systematize and provide an in-depth analysis of the chemical and immunological determinants of allergic reactions to adhesive compositions for eyelash extensions and pigments for brow tinting based on products of American brands, as well as to derive on this

basis scientifically verified protocols for safe application for beauty industry practitioners.

The scientific novelty is defined by an interdisciplinary approach: information from material safety data sheets (MSDS) of commercial products, clinical data on the frequency and structure of adverse events, and basic concepts of the pathogenesis of allergic contact dermatitis are integrated into a single analytical framework, which makes it possible to formulate applied, technologically implementable recommendations.

The author's hypothesis assumes that the observed high frequency of sensitization is due to the predominance in glues of short-chain cyanoacrylates (primarily ethyl-2-cyanoacrylate) and the presence of p-phenylenediamine (PPD) in dyes. These components are considered high-affinity haptens that trigger a type IV cell-mediated immune response. The key modifiable risk factor remains insufficient awareness among technicians of the mechanisms of haptenization, the two-stage dynamics of allergy development, and the methodological limitations of standard patch testing, which jeopardizes the health of both clients and the specialists themselves.

MATERIALS AND METHODS

The study relies on a combined methodology integrating a systematic literature review and content analysis of normative-technical and regulatory documentation. This design connects theoretically verified scientific concepts with empirical information on the composition and safety profile of commercial products.

The theoretical framework was formed on the basis of a targeted search in the peer-reviewed bibliographic databases Scopus, Web of Science, and PubMed. The search strategies incorporated the following key terms and their combinations: eyelash extension allergy, cyanoacrylate contact dermatitis, p-phenylenediamine hypersensitivity, hapten mechanism, cosmetic safety, type IV hypersensitivity. Inclusion criteria comprised publications related to dermatology, ophthalmology, immunology, and toxicology in the context of cosmetic procedures.

The applied component is based on content analysis of publicly available technical documentation, primarily Material Safety Data Sheets (MSDS). Materials were examined for a representative sample of products from leading U.S. brands specified in the query: Xtreme Lashes, Yegi Beauty, and KBL Cosmetics (for adhesives); LB (LashBox LA) and Lash Stuff USA (for lamination systems); RefectoCil USA, Godefroy Tint Kit USA, and Just For Men (for dyes). This approach made it possible to reconstruct the chemical profile of adhesives and dyes and to identify key active components and potential sensitizers.

The integration of data from these heterogeneous blocks enabled an interdisciplinary analysis that links product composition with its biological action and clinical consequences, thereby forming a comprehensive risk and safety assessment in the studied domain.

RESULTS AND DISCUSSION

The study of the chemical nature of professional adhesives for eyelash extensions demonstrates that in the overwhelming majority of cases their functional basis is cyanoacrylic acid monomers, cyanoacrylates [25]. This class of compounds is characterized by an exceptional propensity for rapid anionic polymerization in the presence of moisture (including trace amounts of water on the surface of the natural eyelash), resulting in the formation of a mechanically robust polymer film that ensures durable adhesion of the artificial fiber to the substrate [27].

The most commonly used monomer is ethyl 2-cyanoacrylate (ECA). Its wide prevalence is explained by a favorable balance between high curing kinetics (approximately 0,5–3 s) and the strength characteristics of the formed adhesive joint [25]. Safety data sheet (MSDS) data consistently confirm the dominant proportion of ECA in the formulations of a number of commercial products (as a rule, over 80–90%), including those from the brands Lash Stuff (Black Diamond), LashBox LA (Superhero), Sky Glue S+, and Glad Lash [18].

Critically important for risk assessment is the comparative toxicological profile of various cyanoacrylates. Accumulated experimental evidence indicates an inverse relationship between toxicity and the length of the alkyl chain [13, 14]. Short-chain representatives (SCCA), methyl and ethyl cyanoacrylates, exhibit more pronounced cyto- and histotoxicity; their biodegradation proceeds more rapidly and is accompanied by the release of increased amounts of reactive metabolites, primarily formaldehyde and cyanoacetate, which possess pronounced irritant and sensitizing properties [4]. In contrast, long-chain analogues (LCCA), such as n-butyl and 2-octyl cyanoacrylate, are characterized by slower degradation, greater flexibility, and better biocompatibility, which has led to their use as medical tissue adhesives [16, 23].

Beyond the base monomer, adhesive formulations include functional additives that deliberately adjust the rheology and performance characteristics of the system. Polymethyl methacrylate (PMMA) acts as a polymer scaffold dissolved in the monomer: during cyanoacrylate polymerization it forms a rigid network within the matrix, which leads to an increase in the composition viscosity and an improvement in the mechanical strength of the resulting adhesive joint [25]. The presence of PMMA has been documented, in particular, in the products of Lash Stuff, LashBox LA, and Borboleta [17]. Hydroquinone is used to suppress spontaneous radical processes and stabilize the monomer phase: this free radical inhibitor prevents premature self-polymerization in the container under the influence of light and heat,

thereby extending the material lifecycle and maintaining the reproducibility of its properties [17]. The coloration and optical masking of the bonding area is provided by high-dispersity carbon black (Carbon Black, CI 77266), which imparts the composition with a characteristic black hue and thus facilitates the achievement of an aesthetically uniform result in eyelash extensions [17]. A summary of information from safety data sheets (MSDS) provides the basis for a comparative analysis of the formulations of the most in-demand adhesives in the US market (Table 1).

Table 1. Comparative analysis of the chemical composition of adhesives of leading US brands (compiled by the author based on [17-22]).

Brand/Product	Main cyanoacrylates	Auxiliary components	Declared properties
Lash Stuff (Black Diamond)	Ethyl 2-cyanoacrylate	Poly (methyl methacrylate), Carbon black	-
Borboleta (Go-To Adhesive)	Ethyl Cyanoacrylate, Methoxyethyl Cyanoacrylate	Polymethyl Methacrylate, Hydroquinone, CI 77266	Latex-free, Formaldehyde-free
Glad Lash (Black Adhesive)	Ethyl Cyanoacrylate, Cyanoacrylate (>95% total)	Poly Alkyl Methacrylate, Poly Isocyanate, Pigment	-
Ardell Pro (LashTite Dark)	Methoxyisopropyl Acetate, Nitrocellulose	Alcohol, Diethyl Phthalate, Charcoal Powder	Water-resistant
LashBox LA (Superhero)	Ethyl 2-Cyanoacrylate (85-90%), Methoxyethyl Cyanoacrylate (<5%)	Poly Alkyl Methacrylate (<10%), Pigment	-
Sky Glue S+ (USA distributor)	Ethyl-2-cyanoacrylate	Hydroquinone	-

Comparison of the table data demonstrates a clear gap between the advertising positioning of a number of adhesives and their actual chemical composition. Despite an unequivocal ban, analysis of the product range widely used in American salons reveals a regulatory paradox.

- RefectoCil USA: This brand, known for its versatile palette, in its standard lines contains derivatives of phenylenediamine (including toluenediamines) and is accompanied by standard warnings about the possibility of severe allergic reactions [15].

- Godefroy Tint Kit USA: This product, valued for its capsule format, also uses oxidative dyes in its formulations, including PPD or its derivatives, to achieve the claimed long-lasting effect (up to six weeks).

- Just For Men: This dye, although intended for the beard, is widely used by practitioners off-label for eyebrow tinting. Its popularity is based on the ammonia-free claim, which is falsely associated with overall safety. However, its coloring base often contains toluene-2,5-diamine sulfate (PTDS), a close structural analogue of PPD [19, 26].

The use of these products in the periorbital area indicates a substantial gap between FDA federal directives and actual salon practice. Professionals who employ such agents for eyebrow coloring risk inadvertently violating federal law and jeopardizing the legal and medical safety of both clients and themselves.

Furthermore, the widely used label formaldehyde-free [17] often distracts from what is clinically meaningful. Although formaldehyde is indeed formed as a toxic product of degradation of polymerized cyanoacrylate and is a known sensitizer [4], the leading allergenic potential in the development of ACD is associated with the unstable cyanoacrylate monomer itself, which acts as the primary hapten. Consequently, even an adhesive that initially contains no free formaldehyde remains a pronounced potential allergen due to the nature of its base component. This highlights a systemic deficit in professional training, in which risks are often misjudged: attention shifts to secondary factors while the primary allergen is ignored.

The key factor determining the durability and intensity of permanent (oxidative) dyes for hair and eyebrows is p-phenylenediamine (PPD) and its derivatives, including toluene-2,5-diamine sulfate [10]. PPD is a low-molecular-weight hydrophilic aromatic compound that, during dyeing, undergoes oxidation (typically by hydrogen peroxide) followed by polymerization directly within the hair shaft, forming large chromophoric polymers. The small molecular size and high chemical reactivity confer a pronounced ability to permeate the stratum corneum and to covalently bind to proteins, which predetermines the substantial sensitizing potential of the substance [12].

The regulatory position regarding PPD in the United States remains multilayered and interpretively challenging. For dyes applied to the scalp, the Food and Drug Administration (FDA) allows content up to 6%. At the same time, for procedures in the periocular area the requirements are substantially stricter: the FDA explicitly prohibits the use of PPD and other coal-tar-based color additives for tinting eyebrows and eyelashes; the packaging of such products must bear a

warning about the risk of skin irritation and the categorical prohibition of application to eyelashes and eyebrows due to the danger of blindness [24].

Despite the unequivocal prohibition, an analysis of the product range widely used in U.S. salons reveals a regulatory paradox. Thus, informational materials of the RefectoCil USA brand explicitly indicate the presence of phenylenediamines (toluene diamines) and are accompanied by standard cautions about the possibility of severe allergic reactions [15]. This points to a substantial gap between FDA federal directives and actual salon practice, likely driven by differences in state-level legal regulation and/or insufficient effectiveness of enforcement. Professionals who use such products for eyebrow tinting risk inadvertently violating federal law and jeopardizing the legal and medical safety of clients as well as their own.

Additional uncertainty is created by the PPD-free labeling. In practice, as in the case of some Just For Men formulas or the RefectoCil vegan lines, it often means not a rejection of the class of para-amines, but a substitution of PPD with its structural analog, toluene-2,5-diamine (PTDS). Such analogs exhibit pronounced cross-reactivity: an individual already sensitized to PPD (in particular, after the use of household hair dyes or temporary black henna tattoos) is highly likely to develop an allergic reaction to a PPD-free dye if it contains a derivative of the parent compound. Consequently, choosing an alternative without regard to the chemical relatedness of allergens does not eliminate the risk for a sensitized client.

Allergic contact dermatitis caused by components of cosmetic products represents classical delayed-type hypersensitivity (type IV according to Gell and Coombs) [8, 9]. Unlike immediate type I reactions mediated by IgE, ACD is realized by cell-mediated mechanisms, developing 24–72 hours after exposure to the allergen and proceeding through two strictly demarcated stages: sensitization and elicitation [7].

The key mechanism of ACD pathogenesis is haptenization. Small chemical molecules with molecular mass <1 kDa, such as cyanoacrylate monomers and PPD, are chemically reactive but by themselves are too small to be recognized by the immune system as antigens; they are classified as haptens. To initiate an immune response, a hapten must covalently and irreversibly bind to an endogenous protein carrier in the skin—for example, to epidermal keratin or to albumin of the interstitial fluid. As a result, a hapten–protein complex is formed that has sufficient size and foreignness for antigen recognition [10]. Importantly, certain compounds, in particular PPD, function as prehaptens: they require preliminary activation (for PPD, oxidation by atmospheric oxygen or hydrogen peroxide) to form reactive quinonediimines capable of covalent protein binding [12].

The development of ACD is conveniently represented as a two-phase dynamics, as shown in the diagram (Fig. 1).

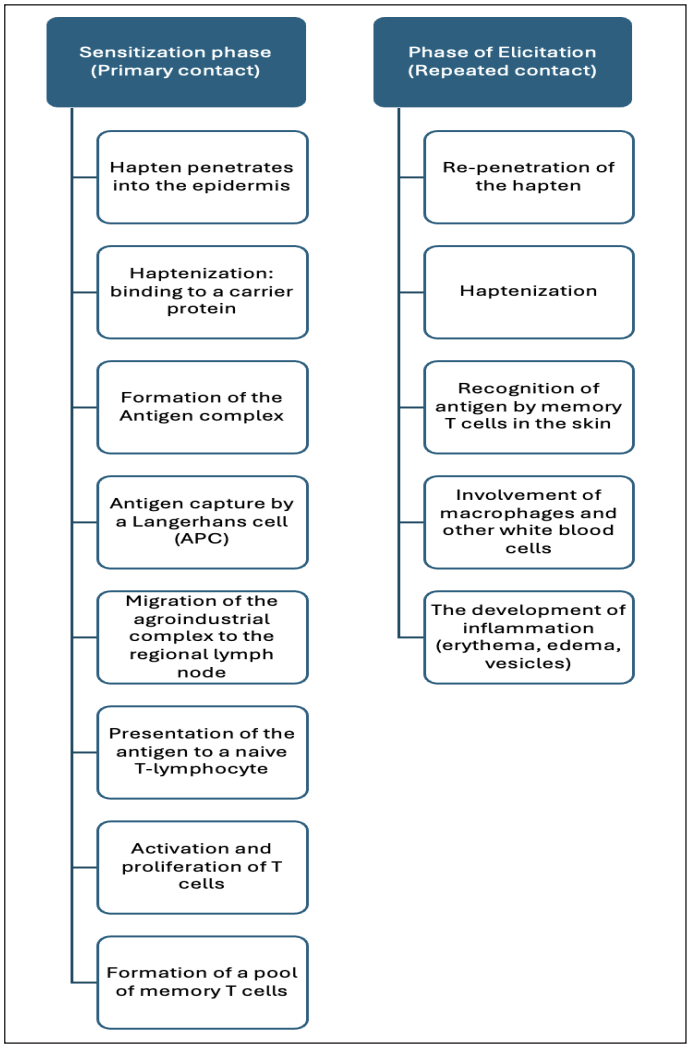

Fig.1. Pathogenesis of allergic contact dermatitis induced by haptens (compiled by the author based on [9]).

The sensitization phase is initiated at the time of first contact with the allergen. A low-molecular-weight hapten, having penetrated the epidermis, covalently modifies cutaneous proteins, forming neoantigenic complexes that are captured by cutaneous antigen-presenting cells, primarily Langerhans cells. These cells then migrate to regional lymph nodes and present peptide–MHC complexes to naive T lymphocytes. The result is activation, clonal expansion, and polarization of hapten-specific T cells (predominantly Th1 and Th17) with concurrent formation of a pool of long-lived memory cells. This stage is clinically silent, and its duration ranges from several days to many years.

The elicitation (resolution) phase arises upon repeated exposure to the identical hapten. Circulating and skin-resident memory T cells rapidly recognize the presented antigen and initiate a fast-evolving cell-mediated response with the release of proinflammatory mediators, including interferon-γ, tumor necrosis factor-α, and interleukin-17. The ensuing cytokine cascade recruits macrophages and neutrophils to the site, inducing local inflammation that manifests after 24–72 hours as erythema, edema, pruritus, and vesicle formation.

The practical significance of the two-phase model is fundamental. A patient may undergo eyelash extension or eyebrow dyeing procedures repeatedly without apparent problems while the immune system imperceptibly completes sensitization. The sudden onset of a pronounced reaction to a familiar formulation does not indicate poor-quality adhesive or a technical error; rather, it points to the completion of the sensitization phase and readiness of the effector response upon re-exposure. Understanding this mechanism necessitates revisiting approaches to counseling, expectation management, and risk assessment.

The clinical presentation of adverse reactions during procedures for eyelashes and eyebrows is variable and determined by the type of product and individual reactivity. For cyanoacrylate adhesives, ophthalmologic and periorbital complications are typical: monomer vapors released during polymerization can cause chemical keratoconjunctivitis with hyperemia, tearing, and foreign-body sensation; direct contact of the adhesive with the eyelid skin or conjunctiva leads to allergic blepharitis, contact dermatitis of the periorbital region, and, in some cases, conjunctival erosions [4]. When dyes containing para-phenylenediamine (PPD) are used, the most characteristic finding is classic allergic contact dermatitis in the eyebrow and eyelid area, developing 24–72 hours after the procedure and presenting with erythema, marked edema, vesicles, intense pruritus, and oozing.

Epidemiological observations confirm the high frequency of such complications. According to a systematic review, allergic blepharitis is the most common adverse outcome associated with eyelash extensions; in individual studies its proportion reached 79% of all recorded cases [4]. In another study that included 400 active users of the service, 54% reported at least one side effect; predominant complaints were pruritus (38%), premature loss of native eyelashes (36%), a sensation of eyelid heaviness (34%), and ocular hyperemia (34%). Summary data on symptom frequencies are aggregated and visualized in a diagram (Fig. 2).

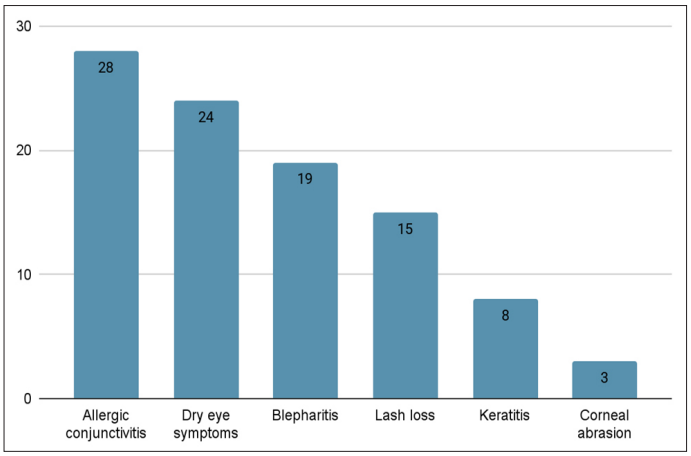

Fig. 2. Prevalence of ophthalmological complications during eyelash extension (%) (compiled by the author based on [4, 5]).

Analysis of the dataset in the FDA MAUDE database for 2023–2024 on medical devices with product code MPN (tissue adhesives, predominantly cyanoacrylate based) revealed cases of adverse events associated with their use in surgical practice. A number of reports describe delayed hypersensitivity reactions developing several days after the intervention that required medical management, including prescription of systemic glucocorticosteroids. Although these observations do not directly relate to the field of beauty services, their indirect significance is high: they confirm the pronounced sensitizing potential of cyanoacrylates in clinical settings. Hence a fundamentally important practical conclusion follows: a client who previously underwent surgical treatment using a skin adhesive (for example, Dermabond containing octyl- and butyl-cyanoacrylates) may already have developed sensitization to this class of substances. Repeat contact — for example, an eyelash extension procedure using an ethyl-cyanoacrylate–based adhesive — is capable of provoking a cross-allergic reaction. This element of the medical history is rarely specifically ascertained in salon practice, although it is of critical importance for safety.

Minimization of risks when working with potentially allergenic materials requires a systematic approach by the practitioner, combining preventive diagnostics, strict adherence to safety regulations, and readiness for emergency actions in the event of adverse reactions.

Patch test (application skin test) — a key preventive instrument for identifying preexisting sensitization to product components. The test is performed by applying a small amount of the product to a limited area of the skin or eyelashes 48–72 h before the main procedure, which allows detection of delayed-type hypersensitivity (DTH) [15]. At the same time, it is important for both practitioners and clients to understand the fundamental limitations of the method.

- False-negative results: A negative patch test does not guarantee the safety of subsequent manipulations; it only records the absence of sensitization at the time of testing. Initiation of sensitization may occur during the main procedure, and clinical manifestations may arise upon subsequent exposures.

- Incomplete allergen coverage: Standard dermatological panels do not include the full spectrum of acrylate monomers employed in the cosmetics industry. Testing with the product itself has greater specificity, but does not preclude omissions. As a screening marker of general acrylate sensitization, 2-hydroxyethyl methacrylate (HEMA) is widely used.

- Technical challenges: A test with cyanoacrylate glue by applying it to the skin (for example, behind the auricle) is incorrect and unsafe: such adhesives are not intended for skin contact and may cause marked irritation or a chemical burn. A more adequate approach is the fixation of several artificial eyelashes to the natural ones; however, such a test is easily unnoticed by the client or may be accidentally removed.

To standardize practice, the following protocol is proposed (Table 2).

Table 2. Protocol for conducting and interpreting a patch test for clients (compiled by the author based on [15]).

Stage	Protocol for adhesive (eyelashes)	Protocol for dye (eyebrows)
1. Preparation	Clean and degrease 3–4 natural eyelashes at the outer canthus.	Clean and degrease a small skin area behind the ear or at the elbow flexure (≈1 cm^2).
2. Application	Apply 3–4 artificial eyelashes with a minimal amount of adhesive, avoiding skin contact.	Prepare a small amount of dye according to the instructions. Apply a thin layer to the prepared skin area.
3. Exposure	The client wears the test eyelashes for 48 hours.	Allow the dye to dry; do not wash off for 48 hours. A patch may be applied.
4. Instructions	Instruct the client to monitor for any reactions: pruritus, erythema, eyelid edema.	Instruct the client to monitor for skin reactions: pruritus, erythema, papules, vesicles.
5. Interpretation	Positive (+): Any discomfort, erythema, edema. The procedure is contraindicated.	Positive (+): Any cutaneous reaction. The procedure is contraindicated.
6. Documentation	Record the result in the client's chart with the client's signature acknowledging review.	Record the result in the client's chart with the client's signature acknowledging review.

Minimizing allergen exposure for the client and the practitioner during the procedure is a fundamental component of prevention.

The workspace must be equipped with an efficient supply and exhaust ventilation system or a local air purifier that provides targeted removal of cyanoacrylate vapors from the breathing zone of the operator and the client.

The practitioner must work in nitrile gloves that provide a chemically resistant barrier for the skin of the hands. Latex should be excluded due to the risk of latex-induced sensitization, and cotton gloves are not considered protective because of the absence of barrier properties against chemical agents. Protective eyewear is additionally recommended to prevent accidental ingress of formulations into the conjunctival sac and onto the cornea [15].

Strict adherence to technique is critical. The adhesive is applied strictly to the natural eyelash with a 0,5–1 mm offset from the eyelid margin, which precludes direct contact of the hapten with the skin. Eyebrow dye should be distributed gently, minimizing its spread beyond the treated area and contact with adjacent skin.

Despite these measures, an acute reaction may occur during the procedure or within the first minutes after its completion; in such a stressful situation, the practitioner needs a clear, easily reproducible action algorithm (Fig. 3).

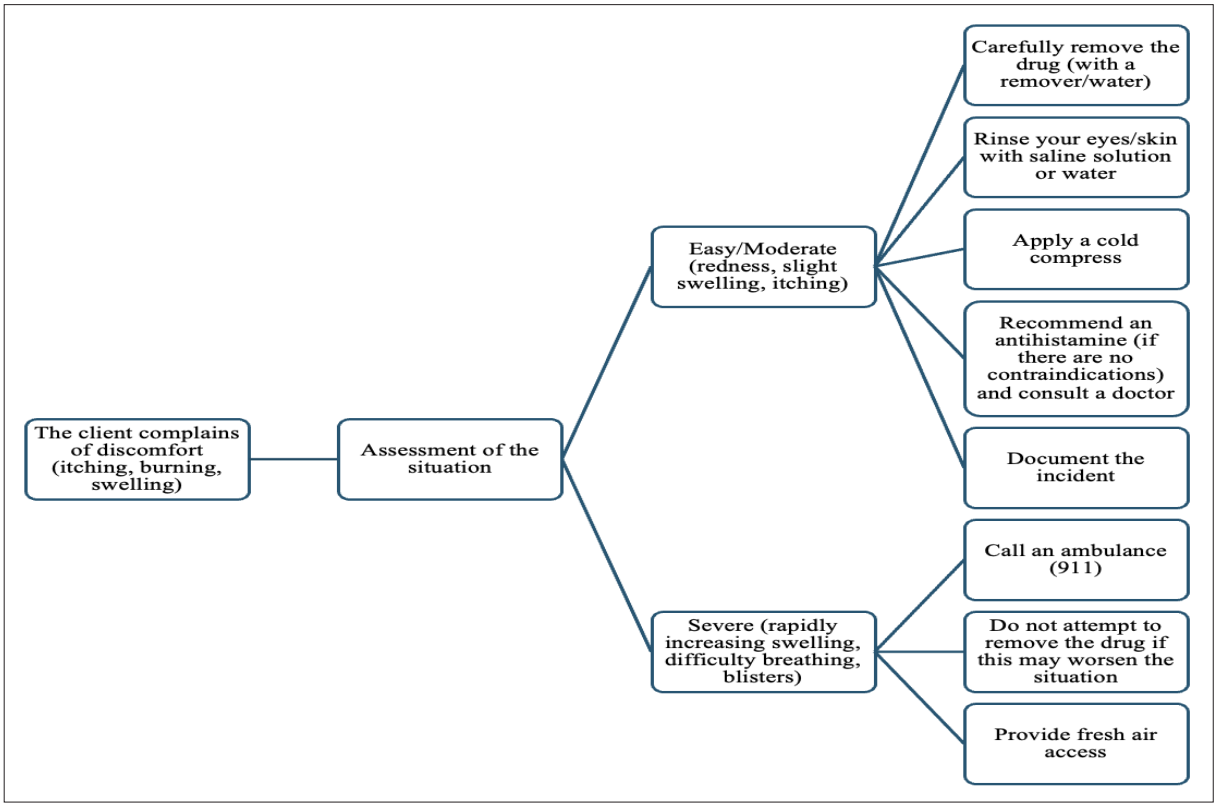

Fig.3. The algorithm of actions of the master in case of an acute allergic reaction in a client (compiled by the author based on [20]).

The algorithm provides rapid stratification of the reaction and the selection of proportionate tactics: from basic first aid for mild manifestations to the immediate calling of emergency services in the development of severe, potentially life-threatening systemic conditions.

CONCLUSION

The analysis performed made it possible to systematize and deepen the understanding of the chemical and immunological determinants of the safety of eyelash extension and eyebrow dyeing procedures. It was established that in eyelash extensions the key chemical risk is associated with the use of adhesives based on short-chain ethyl-2-cyanoacrylate, whereas in eyebrow dyeing it is associated with dyes containing p-phenylenediamine and its derivatives. These components, predominant in products popular on the U.S. market, function as high-affinity haptens and, by covalently binding to skin proteins, initiate a branching cascade of cell-mediated type IV hypersensitivity reactions. The spectrum of observed adverse events, from moderate pruritus to pronounced allergic blepharitis and dermatitis, directly correlates with the physicochemical properties of these substances and their sensitizing potential.

Thus, the stated objective was achieved: a comprehensive consideration of the chemical-immunological mechanisms of allergic responses was carried out, and on this basis specific, scientifically substantiated regulations for safe use were proposed. The regulations include algorithms for performing and interpreting patch testing with due regard for its limitations, requirements for ensuring procedural safety, and a detailed course of action in the event of acute adverse reactions in the client.

The practical value of the work lies in providing beauty industry professionals with tools to transition from intuitive-empirical decisions to evidence-based practice. Implementation of the proposed measures, from expanded medical history taking (including information on previous surgical interventions involving tissue adhesives) and correct interpretation of patch test limitations to explaining to the client the biphasic nature of the allergic process, can significantly reduce health risks for consumers. The results are relevant to cosmetic product manufacturers in developing safer adhesives based on long-chain cyanoacrylates, as well as to educational institutions for updating and deepening training programs for future practitioners. Raising the level of chemical and immunological literacy among specialists appears to be a critical prerequisite for improving the overall safety standard in the beauty industry.

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