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# Optimizing Nail Plate Adhesion: A Comprehensive Technical Protocol for Surface Preparation

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**ABSTRACT**

This study focuses on an integrated analysis of the physicochemical and biomechanical dynamics governing the adhesion of polymer coatings to the natural nail plate. It was specifically the comprehensive retrospective evaluation of 300 clinical cases that provided the empirical evidence to establish the critical importance of maintaining a 10–15% polymer buffer to preserve the integrity of the dorsal layer. This dataset confirms that the etiology of 90% of adhesion loss events is driven by violations of pre-treatment protocols rather than the qualitative properties of the materials employed. Detailed consideration is given to the mechanisms of mechanical interlocking, the correlation between surface microtopography (roughness profile) and bond strength, and the impact of secondary contamination (micro-debris, lipid impregnation) as a catalyst for cohesive failure. The concept of functional protection is introduced, establishing that the preservation of the biological substrate's vital functions, coupled with strict operative field asepsis, serves as the exclusive determinant of the structure's engineering stability. A unique standardized protocol is proposed to mitigate the risk of iatrogenic onychodystrophies.

**KEYWORDS**

*nail plate adhesion, pre-treatment, dorsal layer, selective removal, secondary contamination, functional protection, lateral lifting.*

## Introduction

In the professional environment and among the clientele of nail service practitioners, a prevalent misconception persists - the attribution of coating instability is frequently reduced to a critique of the chemical formulations of products (base coats, top gels), while the critical determinant is overlooked. Nevertheless, the resistance of the artificial material upon the natural plate is the resultant of the physicochemical interaction between substances (Schoon, 2005).

## Literature Review

According to the technical analysis of reclamations, the etiology of 90% of cases involving lifting and delamination lies in the violation of pre-treatment protocols. Adhesion constitutes the establishment of molecular and mechanical bonds between the keratin of the dorsal layer and the oligomers of the base coat. Any infraction at the stage of dehydration or pterygium eradication creates a “buffer zone” that impedes the polymerization of the material directly within the dorsal layer structure, inevitably leading to coating rejection and compromised retention (Madnani & Khan, 2012).

Particular attention is required for the deconstruction of the persistent myth regarding the destructive impact of long-term coatings on the natural nail.

From a chemical perspective, modern polymer systems are inert following complete polymerization. Pathological alterations of the nail plate (onychodystrophy, thinning, hypersensitivity), which clients attribute to the “harmfulness of gel polish”, are in the absolute majority of cases of an iatrogenic nature (induced by the practitioner’s actions) (Rieder & Tosti, 2016). Aggressive mechanical ablation of the dorsal layer, over-filling of the stress points and chemical burns resulting from the improper selection of primers constitute the veritable causes of keratin structure degradation (Lipner, 2021).

Ultimately, any artificial system mandates a stable substrate. Without correct preparation of the dorsal layer, practitioners attempt to erect a monolithic polymer construction upon a mobile, hydrophilic and lipid foundation, which a priori contradicts the laws of physics and, certainly, the health safety of the client’s nails. In this context, the professional objective of the specialist is to modify the surface in such a manner as to transform biological tissue into an ideal foundation for covalent bonding, without compromising its vital functions and protective barriers.

The aspect of client safety and health warrants separate mention. Ultraviolet radiation from curing lamps, excisional cuticle manicures, inadvertent dermal lacerations, unsterilized instruments and expired or low-quality substandard products - all may provoke the development of local and systemic pathologies (Beylin et al., 2025). The practitioner must monitor all operational nuances, as the final result and the assurance of the client’s health (and their satisfaction with the nail service) depend precisely on every detail of each procedural stage.

## Problem Statement

The purpose of this study is to develop and scientifically substantiate a comprehensive standardized protocol for preparing the natural nail plate surface to achieve optimal polymer coating adhesion, emphasizing the preservation of a 10-15% dorsal layer buffer, selective removal technique, strict control of secondary contamination, and functional protection of the biological substrate, to minimize iatrogenic damage, prevent lifting/delamination, and eliminate long-term nail plate dystrophy.

## Methods and Materials

The relevance of this study is predicated on the prevalence of marketing narratives over technological standards, where failures in coating retention are erroneously attributed to material quality rather than to practitioner violations of preparation protocols. The absence of a unified, scientifically substantiated pre-treatment regulation results in widespread iatrogenic trauma to nail plates (thinning, chemical burns, onycholysis) (Reingold et al., 2025). Consequently, the development of a standardized protocol, predicated on the laws of physics and chemistry, constitutes an imperative measure for risk minimization and the enhancement of procedural safety.

The scientific novelty of the research resides in its focus on an engineering approach to substrate preparation. For the first time within professional discourse, the concept of “functional protection” is introduced and substantiated, where the retention of a 10-15% polymer foundation (selective removal technique) is postulated as a requisite damping element of the structural assembly. Furthermore, a matrix of secondary contamination factors (micro-debris, lipid impregnation, tactile contact) is systematized for the first time as the primary cause of covalent bond disruption and the term “capillary pump” is proposed to delineate the mechanism of lateral lifting development. The study demonstrates that the determinant of adhesion is not the chemical aggressiveness of the primer, but rather the sterility and microtopography of the roughness profile.

The research is founded upon a comprehensive theoretical-clinical analysis of adhesion protocols within the nail service industry. The methodological basis of the work comprises a synthesis of data from the chemistry of high-molecular compounds (polymers), the biomechanics of keratin structures and dermatology (Prudkin et al., 2024). The substantial volume of this retrospective cohort (300 cases) served as the decisive factor that allowed for the identification of the direct correlation between the preservation of a 10-15% buffer layer and the prevention of dorsal layer degradation. The diagnostic instrumentation included visual macro-analysis of the lateral sinuses, palpatory assessment of nail plate rigidity to determine the integrity of the dorsal layer and differentiation of detachment types (adhesive vs cohesive). The technical phase of the experiment involved the validation of the “selective removal” and “mechanical interlocking” protocols utilizing 180-240 grit abrasive systems and diamond-coated rotary instruments.

The limitations of this protocol pertain to the clinical status of the nail apparatus. The proposed methodology is valid for healthy nail plates and is not applicable in cases of acute bacterial or fungal infection (onychomycosis) requiring pharmacological treatment and total elimination of the coating (Tosti & Piraccini, 2008). Furthermore, the protocol presents limitations when treating clients with a history of hormonal dysfunction or dermatological pathologies (psoriasis, eczema) that influence the rate of keratin desquamation and the chemical composition of sebum.

Moreover, the efficacy of the methodology is directly dependent upon the practitioner’s manual dexterity and precision in adhering to abrasive gradations, thereby precluding the automation of the process without the intervention of a qualified specialist.

## Results and Discussion

### Initial diagnostics and atraumatic product removal protocols

The success of the adhesion procedure is determined long before the polymer application, as early as the stage of the primary clinical assessment of the hand status. Disregarding physiological idiosyncrasies, such as hyperhidrosis or xerosis, constitutes a fundamental error leading to the incorrect selection of preparatory chemistry and improper subsequent operational methodology. Excessive moisture associated with hyperhidrosis creates a hydrophilic film acting as an antagonist to hydrophobic artificial materials, necessitating the application of potent dehydrators or, in certain instances, methacrylic acid-based acid primers (Zaias, 1990).

Conversely, working with xerotic, dehydrated skin and involuted nails precludes aggressive dehydration, which may precipitate critical fragility of the free edge.

The process of removing old coatings within the framework of evidence-based practice is predicated on the imperative of preserving the histological structure of the dorsal layer. This is the uppermost, most keratinized layer of the plate (merely 0.3-0.5 mm in thickness), where keratin fibers are densely packed and linked by robust disulfide bonds. It is precisely this layer that ensures 100% of the adhesion potential (Haneke, 2015). During total abrasive stripping of the nail “to zero”, the practitioner inevitably exposes the intermediate layer - a structure comprising loose, “soft/gentle” keratin possessing high hydrophilicity and low cohesive strength. On such a foundation, the polymer chain cannot form a stable bond, leading to inevitable detachment (Baran & Berker, 2019).

Figure 1 demonstrates the disparity in adhesive potentials and their impact on the anatomy of the nail plate.

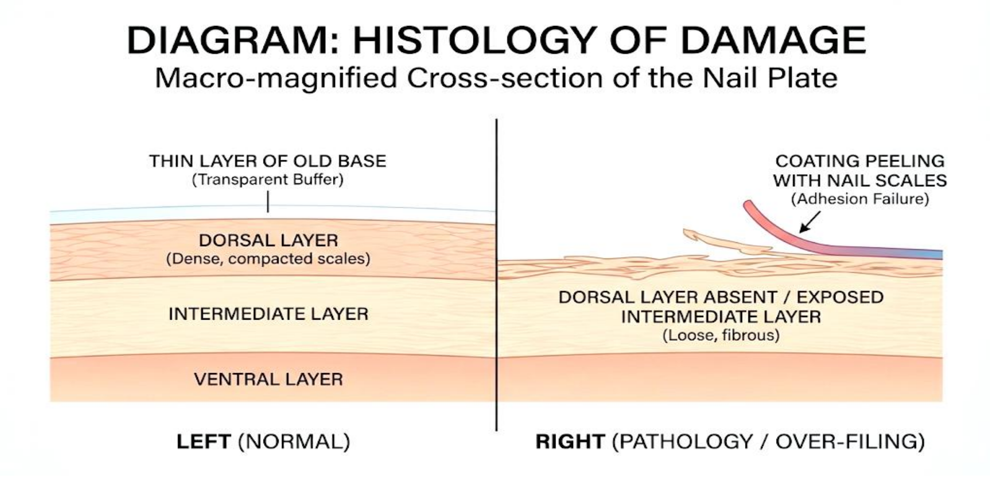


***Figure 1. Differential adhesive potential: dorsal layer (stable bonding) vs intermediate layer (risk of delamination)***

Consequently, the gold standard of pre-treatment is the selective removal technique (see: Figure 2. Diagram of the selective removal methodology). The rotary instrument must operate exclusively upon the artificial material, retaining 10-15% of the polymer substrate (in the absence of lifting). This residual layer performs the function of a damper. It attenuates vibrational loads on the matrix, prevents mechanical ablation of the natural keratin and serves as a thermal insulator, shielding the sensitive nail bed from the exothermic reaction during the polymerization of the new portion of the base coat (Scher & Daniel, 2018). Verification of the residual layer thickness is conducted palpatorily and with caution. The preservation of plate rigidity under vertical pressure indicates the integrity of the dorsal layer, where elastic deformation (the "spring effect") and hyperemia of the bed constitute markers of iatrogenic thinning, necessitating a transition to a restorative protocol.

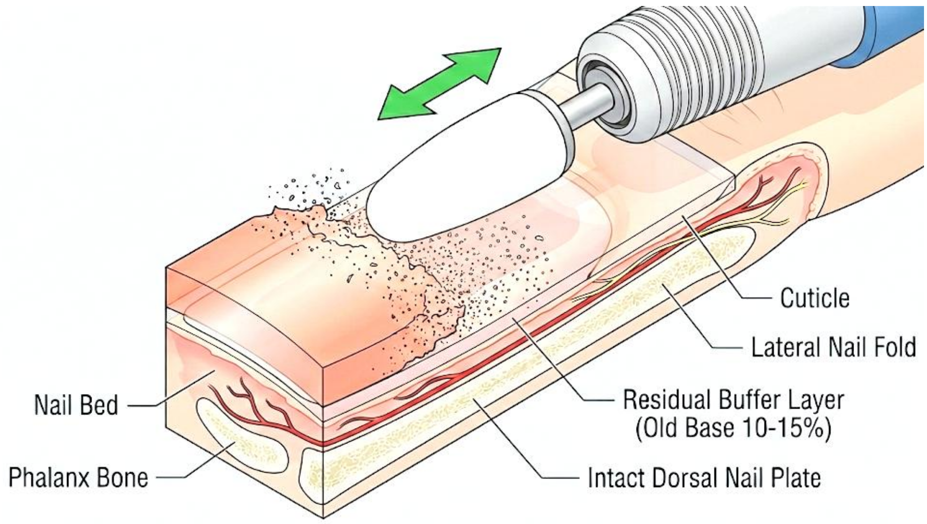


***Figure 2. Schematic visualization of the selective removal methodology. The rotary instrument operates within the upper strata of the coating, leaving a thin protective layer of the base polymer intact, thereby guaranteeing the preservation of the dorsal layer of the natural nail***

Strict adherence to the dorsal layer preservation protocol guarantees the invariance of the nail plate thickness irrespective of the duration of artificial coating usage. In this scenario, the concept of nail resting loses its physiological validity, as the destructive impact on keratin structures is reduced to zero. The practitioner employing the selective removal technique ensures the functional protection of tissues, precluding the risks of acquired dystrophy even in the long-term perspective.

## Nail architecture and mechanical plate preparation

Following the stage of atraumatic coating removal, the procedure transitions into the phase of engineering construction, where the aesthetic form remains subordinate to the laws of biomechanics. In professional understanding, the filing of the free edge constitutes the creation of a geometrically calibrated structure capable of resisting dynamic loads.

From the perspective of physics, the free edge of the nail represents a lever and the longevity of the future architecture correlates directly with axial symmetry - the precise alignment of the central axis of the phalanx and the longitudinal axis of the nail plate. Any deviation of the lateral parallels or displacement of the apex disrupts the uniform distribution of kinetic energy during routine mechanical impacts and compression, provoking a torsional twisting effect (Farren et al., 2004). Under such deformation, the nail begins to bend spirally, creating zones of critical stress, where the disparity in the moduli of elasticity between natural keratin and the rigid polymer inevitably leads to cohesive fractures at the stress points and lateral lifting.

Parallel to geometric modeling, the preparation of the dorsal surface for bonding takes place. A fundamental error at this stage is the application of high-grit buffing blocks (exceeding 240 grit), which smooth the micro-relief and seal the keratin scales, critically reducing the surface energy of the substrate. Modern adhesive system chemistry is based on the principle of mechanical interlocking, that is, the physical infiltration of base oligomers into the micro-irregularities of the nail (Awaja et al., 2009). To facilitate this process, an abrasive in the 180-240 grit range is required, capable of forming a specific “roughness profile”. Only such a texture ensures a sufficient increase in contact area for the formation of a reliable adhesive chain (Azari et al., 2010).

The objective of mechanical treatment is the modification of the nail plate topography - the so-called “raising” of dorsal onychoblasts. The operating technique implies strictly superficial, unidirectional abrasive movements (methods “towards oneself” or “distally from the cuticle”), which allows for the elevation of keratin scale edges, creating multiple “anchor zones” for the polymer. The depth of such modification must not exceed the thickness of 2-3 cellular layers. Exceeding this limit or employing chaotic filing movements (“sawing back and forth”) destroys the structural integrity of the dorsal layer and exposes the hydrophilic intermediate keratin, to which adhesion is chemically impossible. The result of the correct protocol should be a uniformly matte, whitish surface that has retained its original rigidity, but acquired the necessary retentive properties.

Figure 3 illustrates the correlation between adhesive strength and the roughness profile of the nail plate in greater detail.

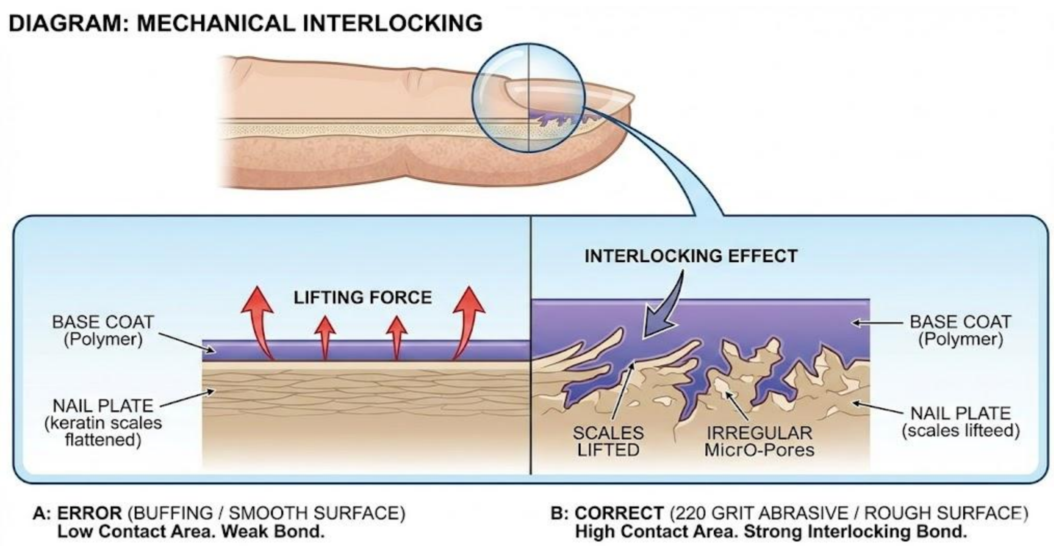


***Figure 3. The principle of mechanical interlocking: the correlation between adhesive strength and the roughness profile. Surface modification utilizing a 220-grit abrasive increases the active bonding surface area by a factor of three relative to a polished surface***

It is further imperative to acknowledge that the process of mechanical surface modification inevitably generates a byproduct - micronized keratin dust (detritus). Possessing a high electrostatic charge, these particles deposit within the freshly created grooves of the “roughness profile”, causing their occlusion. Should the meticulous removal of this substrate be neglected, the polymer base, upon application, will bond not with the monolith of the nail plate, but with the mobile dust layer, resulting in immediate material rejection (the “breading effect”).

Standard soft dusting brushes are rendered ineffective in this context, as they merely redistribute particles across the surface without extracting them from the depths of the retention pattern. The professional protocol mandates the utilization of stiff synthetic bristle brushes (nylon/polypropylene) and a stroke direction strictly “from the cuticle to the free edge” to mechanically dislodge detritus from the opened scales without compromising the established structure.

## The “immaculate manicure”: eponychium management and pterygium eradication

While mechanical surface treatment establishes the conditions for micro-adhesion, operations within the proximal fold (cuticle) zone ensure the hermetic sealing of the system. The fundamental adhesive challenge in this region is the pterygium - a hypertrophied ventral layer of the epidermis that advances onto the nail plate concomitantly with its growth (see: Figure 4. Topography of the proximal zone).

From the standpoint of polymer chemistry, the pterygium constitutes a biological substrate defect. It is a tissue saturated with lipids and moisture, characterized by a high rate of desquamation. The application of artificial material onto even microscopic residues of this tissue (so-called “latent pterygium”) is fatal for coating retention. Consequently, the base coat polymerizes not upon the stable nail keratin, but on necrotic skin cells, which slough off after 3-4 days, thereby precipitating detachment in the lunula zone (Rigopoulos & Elewski, 2021).

Overall, a critical preparation stage is the elevation of the proximal pocket and sinuses. This manipulation borders on microsurgery, as it is performed in a “blind zone” directly above the matrix - the germinal zone of the nail. The matrix, concealed beneath the eponychium, consists of soft, non-keratinized cells (onychoblasts) lacking protective density. Any incorrect pressure applied by a pusher or rotary bit (particularly at an angle exceeding 45 degrees) results in traumatic compression of the nail root (Maddy & Tosti, 2018). The clinical manifestation of such an error presents as transverse grooves (Beau’s lines) or parakeratosis, visible only as the plate grows out. Therefore, the protocol mandates the use of bits with a safe (blunt) tip and operation exclusively on dry pterygium, avoiding contact with the ventral surface of the proximal fold.

The selection of the resection method for the keratinized cuticle edge (hardware/rotary or combined/cutting instrument) is dictated solely by skin type, rather than the practitioner’s personal preference, as is frequently observed due to a lack of proficiency in hardware manicure techniques. When examining “cleanliness” for adhesion, it becomes evident that the priority is the quality of the subcuticular space debridement. Hardware resection (diamond ball/flame) is effective on dry, parchment-like skin, providing a polishing effect and retarding regeneration. However, on moist, elastic, or “rubbery” cuticle, the rotary instrument often leaves micro-fraying (shredding), which is impermissible. In such instances, the combined technique (scissors/nippers) ensures a surgically precise cutting edge, minimizing the risk of sebum transfer onto the degreased plate during regrowth.

The outcome of this stage must be a fully cleared sinus and a visualized strip of clean dorsal layer beneath the cuticle, ready for polymer application “flush” or “subcutaneously” without the risk of material contact with the epidermis.

Figure 4 most vividly demonstrates that the rotary instrument must traverse exclusively parallel to the surface of the nail plate, without inclination. As indicated by the second incorrect variant, angulation of the bit precipitates mechanical trauma and induces pain in the client.

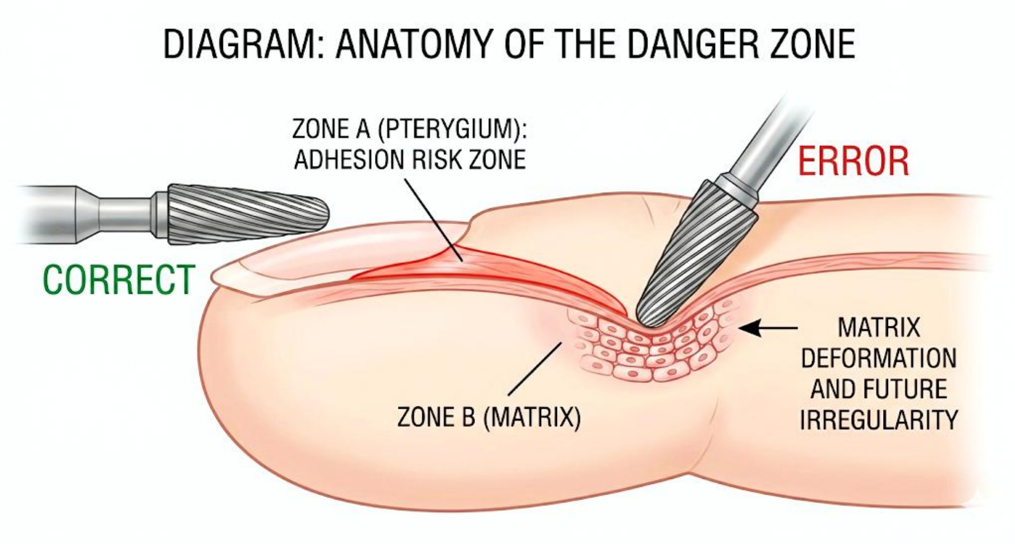


***Figure 4. Topography of the proximal zone: pterygium as a lipid barrier to adhesion and vectors of safe rotary instrument operation over the matrix zone***

It is additionally necessary to note the factor of hemostasis and exudation. The pursuit of a “deep” manicure frequently leads to micro-trauma of the eponychial capillaries. Even if hemorrhage is visually absent, the traumatized tissue begins to secrete lymphatic exudate (interstitial fluid). This biological fluid serves as a potent electrolyte and contains proteins that instantaneously create a moist film on the nail surface in the sinus zone (Sanaat et al., 2021). An attempt to apply a base coat onto the nail immediately following a micro-laceration, even one treated with a hemostatic agent, is doomed to failure. The exudate will destroy the covalent bond within 48 hours.

Therefore, a “clean” manicure in the professional understanding is, first and foremost, an atraumatic manicure that maintains the dryness of the operative field and, certainly, ensures the health safety of the client’s nail plate.

## Chemical fundamentals: optimizing molecular adhesion and bonding systems

The final stability of the polymer system on the natural plate is contingent not only upon the correctness of application protocols but also, with equal criticality, upon the practitioner’s capacity to maintain absolute cleanliness of the operative field up to the moment of complete polymerization.

Technical analysis of instances of early delamination (detachments within the first 3-5 days of wear) indicates that in 95% of cases, the etiology is secondary contamination. This constitutes a contamination of the prepared surface imperceptible to the naked eye, establishing a microscopic barrier between the keratin and the artificial material.

The primary critical risk factor is deep lipid saturation of the dorsal layer. This occurs when the client utilizes, for instance, occlusive creams, paraffin therapy, or cuticle oils less than 24 hours before the procedure. Molecules of lanolin, mineral oils and silicones penetrate deeply into the structure of porous onychoblasts, creating a hydrophobic interlayer within the nail itself. Standard surface degreasing with a cleanser is incapable of emulsifying and extracting these lipids from the depth (Rosik et al., 2025). In such instances, adhesion occurs solely to the superficial, degreased layer, which subsequently detaches from the lipid-impregnated internal layer (cohesive fracture). The resolution to this issue is, certainly, the admonition of the client regarding the prohibition of lipid-rich textures before the appointment or the employment of prolonged dehydration should the requirement not have been observed on the eve of the procedure.

The second most prevalent agent of adhesion disruption is residual micro-detritus within the lateral sinuses. Dust remaining after filing and hardware treatment within the deep folds of the lateral ridges constitutes a hygroscopic substrate. If the practitioner applies the base coating without ensuring the total evacuation of dust, the polymer bonds not with the nail plate, but with a loose conglomerate of filings. This zone transforms into a “capillary pump”. During wear, this region actively absorbs moisture and cutaneous sebum, provoking the hydrolysis (degradation) of bonds and the development of lateral onycholysis.

Finally, the most stringent violation of adhesion asepsis is tactile contact with the prepared plate. Touching the nail with the practitioner's or client's finger following the degreasing stage (even to verify "smoothness") instantaneously transfers cutaneous sebum and epidermal lipids onto the surface. This locally reduces surface energy to a critical minimum, rendering chemical bonding at the contact point impossible. The professional standard dictates the "No touch" rule: following the application of the dehydrator, any contact with the nail plate is permissible exclusively via a sterile brush carrying polymer material.

*Table 1. Matrix of secondary contamination factors*

| Etiological factor (agent) | Failure mechanism | Clinical manifestation | Prevention protocol |
|---|---|---|---|
| Micro-debris (residual dust in lateral sinuses) | Formation of a hygroscopic interface layer. "Capillary pump" effect, aspirating moisture beneath the base coat | Lateral lifting (detachment at stress points). Formation of "pockets" after 3-5 days of wear | Application of stiff synthetic brushes (nylon/polypropylene). Strokes are strictly "distally from the cuticle" |
| Tactile Contamination (violation of "No touch" rule) | Immediate transfer of the lipid mantle. Critical reduction of surface energy. Formation of a hydrophobic barrier film | Local "bubble-type" detachment (often central or apical). Immediate rejection during polymerization shrinkage stress | Absolute prohibition of tactile contact. Manipulation exclusively via sterile instruments post-dehydration |
| Lipid impregnation (creams/oils usage) | Deep saturation of onychoblasts with fatty acids /silicones. Inhibition of covalent bonding with internal keratin layers | Cohesive failure (delamination of material together with dorsal keratin scales). Total coating rejection | Pre-procedural anamnesis. Prohibition of lipid-rich products 24h prior. Protocol of prolonged double dehydration |

It is imperative to comprehend that any photopolymeric material, during the curing process (the phase transition from a liquid to a solid state), undergoes volumetric contraction, thereby inducing internal stress at the "nail-material" interface. Provided that the preparation is executed with perfection, the magnitude of the covalent chemical bond surpasses the force of shrinkage, ensuring the coating maintains a monolithic bond. However, should the aforementioned contamination agents (lipids, particulate matter, moisture) be present on the surface, the adhesion strength is compromised (Khudyakov et al., 2003).

At this juncture, the internal stress of the material, analogous to a tensioned spring, shears the coating from the compromised zones, propagating a microscopic preparation defect into a full-scale delamination. Absolute cleanliness constitutes the sole mechanism to counteract the physics of material shrinkage, as visualized in Figure 5.

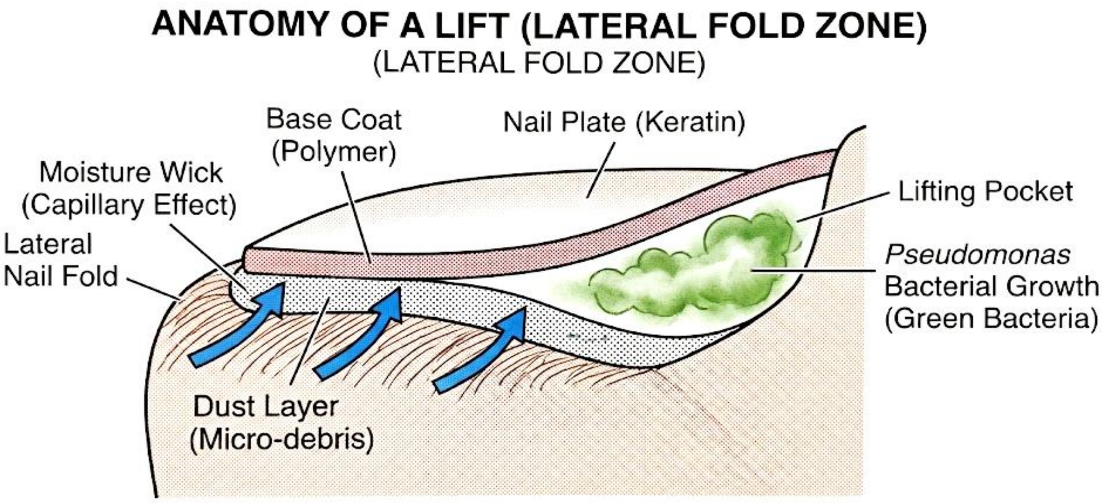


*Figure 5. Pathogenesis of lateral lifting: micro-detritus as a moisture conductor and a medium for bacterial colonization*

## Conclusion

Based on the comprehensive analysis of the physicochemical and biomechanical aspects of adhesion within the nail service domain, it is postulated that the formation of a resistant polymer coating on the natural nail plate constitutes a multifactorial process, the success of which is determined by strict adherence to technological regulation. The study established that the dominant cause of destabilization in the keratin-polymer system (in 90% of cases) is the violation of pre-treatment protocols, resulting in the inability to achieve thermodynamic equilibrium at the phase interface.

Furthermore, the necessity of transitioning to a technique of “selective preservation” of the dorsal layer’s histological architecture is substantiated. It is demonstrated that this layer, possessing maximal keratinization density and an optimal modulus of elasticity, serves as the sole reliable substrate for covalent bonding. It's iatrogenic destruction or attenuation inevitably exposes the hydrophilic intermediate layer, substantially reducing adhesive potential and provoking the development of onychodystrophies.

Within the framework of the investigation into mechanical interlocking mechanisms, it is confirmed that the modification of nail microtopography for the purpose of creating a developed roughness profile must be accompanied by the absolute evacuation of micronized detritus, the presence of which causes occlusion of retention pores and forms a “weak link” in the adhesive chain.

Special attention is accorded to the chemical aspects of the interaction between the hydrophilic biological substrate and the hydrophobic polymer matrix. It is revealed that the key condition for wettability and subsequent polymerization is the temporary modification of the nail’s surface energy via dehydration and the application of adhesion promoters, alongside the complete elimination of the lipid barrier. Factors of secondary contamination (residual pterygium, cutaneous sebum, exogenous lipids) are categorized as critical inhibitors of adhesion, precipitating bond hydrolysis and bacterial colonization within the lateral sinuses.

Summarizing the foregoing, it is concluded that ensuring the long-term integrity of the coating and the biological safety of the client is achievable exclusively through the implementation of the functional protection strategy.

In this paradigm, the practitioner is positioned as the operator of a complex biotechnological process, where priority is assigned to the preservation of the vital functions and barrier properties of the natural plate, serving as the sole guarantor of the engineering stability of the final assembly.

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