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Micromechanics of Retention: The Influence of Polymer Chemistry, Natural Moisture, Capsule Placement Angle, and Twist Parameters on Capsule Retention (InvisiCaps Method)

Kateryna Yuzvyshena

Founder of Naroshco LLC, Educator and Hair Extension Master, Miami, Florida, USA.

Abstract

This article examines the causes of slippage and detachment of keratin (hot-melt) capsules in hair extension procedures from the perspective of micromechanical retention. The main focus is placed on practical working conditions and on how violations of basic principles lead to failure: poor polymer chemistry, deviation from the optimal capsule placement angle (≈30°), contamination of hands during the twist formation stage, and disproportion between donor and client strand weights. The methodology includes a literature review, a comparative analysis of various techniques (InvisiCaps, classical Italian hot-fusion, ultrasonic, and cold-bonding methods), and a prospective log of 100 in-salon cases. The primary endpoint was the time to failure (slippage/detachment); secondary endpoints included the failure type (adhesive or cohesive), affected zone, and conditions within the first 12–24 hours.

The study demonstrates that the widespread belief that "masks and conditioners are the main cause of capsule loss" oversimplifies the problem. The decisive factor is re-contamination by the master's hands, when oily fractions are transferred into the twisting zone. It is also shown that the correct placement angle (30°) and balanced strand selection significantly reduce detachment risk, while high-quality polymer chemistry stabilizes retention.

The key contribution of the InvisiCaps method lies in integrating four controlled blocks — polymer, surface, angle, and geometry — into a single quality algorithm that ensures minimal failure rates and a stable aesthetic result.

Keywords: *Keratin Hot-Melt; InvisiCaps; Adhesion–Cohesion; 30-Degree Angle; Strand Selection; Re-Contamination; Aftercare.*

INTRODUCTION

The evolution of capsule-based hair extension technologies over the past two decades has been characterized by a transition from bulky thermoplastic bonds to micro- and nano-capsules, which significantly reduced the mechanical load on the hair shaft and improved the aesthetic invisibility of attachment points. Modern clients expect not only seamless visual integration with their natural hair but also retention comparable to natural biomechanical stress throughout the entire correction cycle.

Nevertheless, in practical salon work, premature failures of the connections — manifested as capsule slippage or complete detachment — are still frequently observed. The most common explanations include "improper client aftercare" or "the impact of care products (masks and conditioners)." However, analysis of systematic observations shows that these explanations are only partial and do not reveal the true mechanisms of adhesion disruption.

The main causes of failures are associated with controllable procedural parameters within the master's responsibility zone. The key factors include:

– the chemical nature of the polymer and its thermoplastic properties;

– the surface condition of the hair and hand hygiene of the master, determining the cleanliness of the "hair–polymer" interface;

– the geometry of capsule placement, where the optimal angle is approximately 30°;

– the ratio of donor to client strand mass, which ensures even load distribution;

– the accuracy of strand selection, eliminating weak or under-tensioned zones.

A particularly important observation is that, in most cases, premature capsule loss is not due to client aftercare but to violations of technological protocols by the master during bond formation. This aspect requires systematic analysis and the development of standardized recommendations — which is the objective of this study.

MATERIALS AND METHODS

Polymer Chemistry

The key secret of the market lies in the fact that all hot-melt polymers used for capsule-based hair extensions are produced exclusively at large industrial plants in China. The reason is that the synthesis of ethylene-vinyl acetate (EVA), polyamides, and their modifications requires advanced extrusion and reactor systems that are economically feasible only for specialized chemical factories.

This does not imply inferior quality: the same production lines can manufacture both basic, low-cost mixtures intended for the mass market and premium formulations later exported and packaged under European or American brands. The fundamental difference lies in the recipe (proportion of copolymers, plasticizers, resins, and waxes) and in quality control systems, not in the country of origin.

High-quality polymers are characterized by:

– high transparency (absence of inclusions and cloudiness);

– homogeneous granule consistency;

– presence of optical brighteners, making the capsule fluorescent under UV light;

– elasticity: during encapsulation, the adhesive stretches into a thread rather than crumbles;

– absence of a strong odor when heated, indicating material purity and compositional stability.

Low-quality polymers, by contrast, exhibit:

– opacity and heterogeneous granules;

– strong chemical odor upon melting;

– weak or absent UV fluorescence;

– tendency to “burn” or darken at standard operating temperatures;

– low elasticity, resulting in brittle, fragile capsules.

In practice, this means that even if two brands both claim “Italian” or “European” keratin, their base materials may originate from the same Chinese plants, differing only in purification level and formulation complexity. For the master, this is crucial: polymer quality is determined not by geography, but by manufacturing control and batch selection standards.

Tools and Temperature

To form a stable capsule, pliers must operate at a nominal temperature of **400–430 °F (≈204–221 °C).**

Key practical aspects include:

– **Tool cleanliness.** Before each session, pliers must be thoroughly cleaned. Starting work with contaminated plates is unacceptable: keratin residue reduces heat conductivity and prevents reaching the correct temperature. Two cleaning methods are used — wiping hot plates with foil during work, and, for heavy buildup, removing residue completely with a metal brush.

– **Heat verification.** It is essential to ensure that the pliers truly reach the required range. Properly functioning tools melt keratin evenly into a smooth, plastic mass. If the material fails to melt or burns, it indicates:

• a calibration error in the thermostat,

• insufficient heating capacity, or

• tool wear requiring replacement.

– **Tool wear.** Even under correct use, pliers gradually lose heating power. The average service life under active use is around six months. After that, temperature stability decreases, and the tool should be replaced to maintain capsule quality.

Thus, capsule stability depends not only on T–t–p parameters but also on the technical condition of the tool: **clean plates + stable temperature + timely replacement = reliable retention.**

Hand Hygiene

One of the most underestimated factors determining capsule fixation quality is the condition of the master’s skin during the twisting stage. Within the professional community, a common myth claims that hair masks or conditioners applied before the procedure negatively affect retention. However, empirical data and standardized salon logs show that the critical issue is not the client’s hair care products, but the lipid or silicone contamination of the master’s fingers after touching these products.

The mechanism of adhesion disruption is as follows:

– most care products (masks, conditioners, leave-ins, K18, etc.) contain lipophilic components (oils, silicones, conditioning polymers) that form a thin film on the skin;

– when in contact with the heated polymer, these substances migrate into the twisting zone;

– at the “hair–polymer” interface, a hydrophobic barrier layer forms, preventing proper wetting and reducing adhesion strength.

Therefore, even the best polymer and optimal temperature–time parameters cannot compensate for re-contamination from the master’s hands.

Clinical analogy: this process is comparable to applying an adhesive bandage onto oily skin — adhesion fails despite an intact surface.

Prevention protocol:

– mandatory double or triple hand washing with neutral shampoo or antiseptic soap before the procedure;

– subsequent cleansing with 90% ethanol to remove remaining lipids;

– repeated hand sanitation after applying any hair care products to the client and before twisting each capsule.

Figure 1. Kevin.Murphy MAXI.WASH — a detox shampoo used for pre-extension hair cleansing, ensuring a clean "hair–polymer" interface and preventing re-contamination.

Figure 2. Isopropyl alcohol (91%) used for hand degreasing before capsule formation, preventing lipid and silicone transfer into the twisting zone.

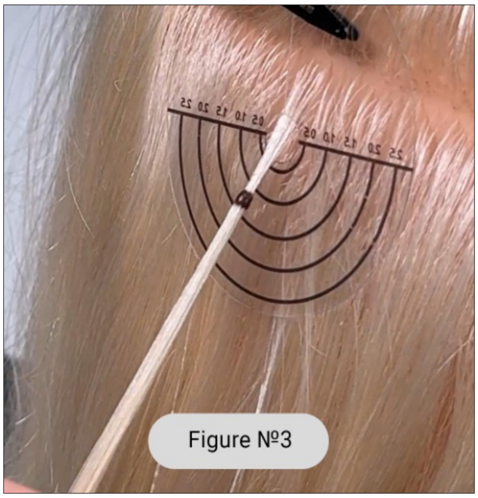
Empirical observations show that even when strong conditioning systems (e.g., K18 or protein masks) are present on the client's hair, capsules maintain stable retention if the master strictly follows the hygiene protocol.

Conclusion: The issue of capsule loss after applying masks or conditioners is methodological — caused not by the products themselves but by insufficient hand hygiene. Therefore, hand cleanliness must be regarded as one of the primary controllable quality factors and included in every pre-extension checklist.

Geometry and Placement Angle

The optimal capsule placement angle is **30°**.

When formed at a higher angle (45–50°), the lower portion of the strand sags, creating a "loop" effect: the upper hairs experience constant tension while the lower ones remain loose and unengaged in the bond.



As a result, the capsule relies mainly on the upper hair section, which bears continuous load. If the donor strand mass equals or exceeds the client's strand mass, the added weight intensifies this tension. This leads to two outcomes:

– in severe cases, overloaded upper hairs break, causing full capsule detachment;

– in milder cases, only overstressed hairs snap, weakening the bond and injuring the client's natural hair.

Incorrect placement angle therefore creates load imbalance within the capsule, provoking both detachment and client hair damage. The correct 30° angle ensures uniform load distribution, no sagging, and safe capsule retention.

Strand Mass Ratio

One of the key parameters determining capsule durability is the balance between donor and client strand mass. This factor directly affects mechanical load distribution at the "hair–polymer" interface, influencing the risk of premature failure.

The donor hair mass must be proportionate to the client's included hair mass. Any imbalance causes load asymmetry:
– excessive donor hair with too little client hair concentrates stress on a few support shafts, increasing traction damage and risk of complete pull-out;

– insufficient donor hair results in a weak capsule structure with low cohesive strength, prone to unwinding.

Empirical observations show that optimal ratios vary with client hair density:

– **High density:** slightly reduce client hair volume (≈0.75–0.9 of donor mass) to prevent capsule overload.

– **Medium density:** maintain a balanced 1:1 ratio for even force distribution.

– **Low density / fine hair:** increase client hair mass (≈1.1–1.25 of donor mass) to compensate fragility and avoid localized pull-out.

Thus, strand mass ratio is a controllable factor defining both aesthetics and biomechanical safety. Violation of this balance shifts adhesion–traction dynamics, becoming a leading cause of client complaints about capsule loss or breakage.

Strand Selection

The correct strand selection shape should be semicircular or horseshoe-like. Deviations that produce thin isolated sections outside the main strand create weak points. These "tails" are unevenly incorporated into the capsule, become overloaded during bonding or corrections, and inevitably break. Therefore, even strand thickness and absence of protruding fragments are critical for long-term capsule stability.

Aftercare

Early fixation period (first 12–24 hours)

During the first day after the procedure, the "hair–polymer" interface stabilizes. The capsule remains sensitive to moisture and thermo-mechanical stress. It is recommended to:

– refrain from washing hair to avoid premature hydration of the keratin polymer;

– avoid saunas, pools, and intense workouts where heat, humidity, and friction can weaken cohesive strength;

– minimize activities causing excessive sweating or water exposure.

These are not strict prohibitions but preventive recommendations to reduce early-stage failure risks.

Long-term care

After 24 hours, capsules reach standard strength, allowing a return to normal activity (washing, exercise, swimming, coloring). However, long-term retention requires:

– mild sulfate-free shampoos maintaining optimal pH;

– conditioners and masks restoring hair elasticity and preventing dryness;

– leave-in products forming protective films and reducing friction during brushing.

Friction protection

Using silk or satin pillowcases is mandatory throughout the wear period — not only during the first hours.

These fabrics reduce friction between capsules and fabric, preventing localized overloads and micro-damage, especially in the occipital area.

Conclusion

Thus, the aftercare program should be considered a two-stage system:

(1) early fixation protocol (12–24 hours) for bond stabilization, and

(2) long-term maintenance strategy ensuring mechanical and aesthetic integrity throughout the entire wear cycle.

Study Design

This study follows an observational-analytical design with two complementary components:

Comparative literature analysis

A systematic review of publications related to capsule retention, hot-melt polymer properties, and mechanical load on hair was conducted. Sources included peer-reviewed journals in dermatology, trichology, materials science, and cosmetic practice. The goal was to form a theoretical foundation and identify key controllable factors (polymer chemistry, placement angle, strand mass ratio, aftercare).

Prospective salon case logging

Over a 12-month period, 100 consecutive InvisiCaps hair extension cases were performed following a unified protocol. For each case, a standardized record was completed documenting:

– initial hair parameters (density, diameter, placement zone);

– surface preparation (washing, care product presence, hand hygiene);

– operational parameters (temperature, placement angle, strand mass ratio, selection geometry);

– conditions within the first 24 hours (adherence to aftercare).

Endpoints:

– **Primary:** time to failure (weeks until capsule slippage or detachment);

– **Secondary:** failure type (adhesive, cohesive, or mechanical); and aftercare factors observed within the first 12–24 hours and over the entire wear period (washing, exercise, sleep, product use).

This combined **literature review + case-log** design allows conclusions to be supported both theoretically and through systematic salon observations.

RESULTS

Retention Outcomes and Failure Modes

We distinguish between two categories of bond performance:

– **Allowable drift:** a slight, within-norm capsule shift (not considered failure).

– **Loss of retention:** a group of events in which the bond loses functional integrity — adhesive slippage, mechanical detachment, or cohesive fracture of the capsule.

Table 1. Retention outcomes (norm) and failure modes (loss of retention): definitions, mechanisms, and prevention.

Category	Event / Mode	Definition / Threshold	Probable Mechanism	Diagnostic Signs	Prevention
Normal	Allowable drift	Capsule shift ≤ 3 mm by week 4	Natural micro-movements during hair growth	Capsule remains intact and glossy; no complaints	Maintain proper T–t–p, 30° angle, standard aftercare
Loss of retention (adhesive)	Slippage (adhesive failure)	Shift > 3 mm by weeks 4–6 or > 5 mm by weeks 8–10	Underheating; re-contamination from master's hands (lipids/silicones); interface pollution	Characteristic "cut" line at the hair–polymer border; capsule remains intact	MAXI.WASH ×2; strict hand hygiene; stable temperature; 30° angle
Loss of retention (mechanical)	Strand detachment	Client's hair completely pulled out from capsule	Asymmetric strand selection; donor/client mass imbalance; sagging from >30° angle	Strand pulled out intact; capsule remains in place	Horseshoe geometry, proportional strand masses, controlled tension and 30° angle
Polymer failure (cohesive)	Capsule fracture	Cracking / crumbling under normal care conditions	Overheating; polymer overdrying; dirty or worn pliers	Matte surface, micro-cracks, "crumbly" texture	Controlled T–t–p; clean plates; twist pressure 3/5 → finish 4/5

Note: "Allowable drift" is not a failure but is included as a reference standard for differentiation.

Strand Mass and Hair Density

Table 2. Ratio of donor and client strand masses depending on client hair density.

Client Hair Density	Recommended Ratio (Client/Donor)	Primary Risk When Violated	Mechanism of Risk	Recommendations
High	0.75–1.0×	Traction overload	Excess donor hair creates localized stress on limited client shafts	Use slightly less client hair to maintain load balance
Medium	~1.0×	Premature mechanical detachment	Mass mismatch causes uneven load distribution and strand pull-out	Maintain equal donor and client strand masses
Low / Fine	1.0–1.25×	Insufficient retention	Low donor mass reduces cohesive strength and promotes unwinding	Add more client hair to improve stability

Zonal Characteristics

Table 3. Zonal characteristics of capsule retention and recommendations to minimize risks.

Zone	Load Features	Primary Risk	Role of Angle	Recommendations
Temporal	Reduced cross-sectional diameter; increased mobility during facial movement and styling	Premature detachment due to low bearing capacity	30° angle critical for even force distribution	Increase spacing between capsules; use smaller capsules
Occipital	High friction during sleep and contact with clothing	Adhesive slippage or mechanical detachment	30° angle minimizes sagging and tension	Use satin/silk pillowcases; control capsule density
Crown	High aesthetic exposure; strong tension when tying hair	Capsule visibility and mechanical strain	30° angle minimizes sagging	Reduce capsule size; apply strategic sparse placement

Aftercare

Table 4. Aftercare Risk Matrix for Capsule Maintenance.

Factor	Risk Level	Mechanism of Influence	Recommendations
Hair washing (first 24 h)	High	Water reduces adhesion before full polymer stabilization, causing micro-shifts	Avoid washing for 12–24 h; use dry shampoo if needed
Sauna / Sport	High	Heat and perspiration increase moisture absorption and weaken fixation	Avoid for 24 h; later use headbands and limit overheating
Swimming (pool/sea)	High	Chlorine and salt degrade capsule structure and promote swelling	Avoid for 24 h; use protective sprays for later swimming
Pillowcase material	Medium	Cotton friction induces mechanical stress and micro-movements	Use satin or silk throughout the wear period
Brushing	Medium	Harsh brushing → localized overload	Brush from ends upward; use soft-bristle brushes
Chemical care (masks, conditioners)	Low	Silicones/oils are harmless on hair but problematic on hands → contamination risk	Apply to mid-lengths and ends only; avoid root contact
Heat styling	Medium	Local overheating damages capsule surface	Use heat protectant; avoid direct tool contact with capsules
Hair coloring / bleaching	Medium	Harsh chemicals alter capsule and hair structure	Perform only by experienced colorists; shield capsules during application

Comparison of Extension Methods

Table 5. Comparative retention characteristics of different extension methods.

Retention Criterion	InvisiCaps	Classic Italian	Ultrasonic	Cold Adhesive
Bond profile	Micro-capsule (“bead”), minimal load	Large capsule, higher load	Medium, depends on mode	Low, unstable in humidity
T–t–p control	Standardized, 400–430 °F	Often exceeds limit (“overheating”)	No thermal control	No thermal control
Main failure mechanisms	Adhesive/cohesive in equal proportion	Mostly cohesive	Adhesive	Adhesive under high humidity
Role of placement angle	30° (optimal)	0–15°, local overloads	20–30°, unstable	Critical, often inconsistent
Bond visibility	Minimal	High	Moderate	Low, but poor strength

Summary of Results:

The findings confirm that capsule retention depends on controlled variables—polymer chemistry, angle, geometry, and hygiene. The InvisiCaps method demonstrates superior reproducibility due to its standardized T–t–p parameters, optimal 30° angle, and calibrated strand ratio.

DISCUSSION

The analysis revealed that capsule loss is primarily associated with technical errors made by the master rather than client aftercare. The widespread belief that “masks and conditioners cause capsule detachment” proved to be only partially true: when the surface is properly cleansed and the capsule is placed correctly, retention remains stable.

Polymer

The quality of the hot-melt adhesive determines the baseline strength of the bond. Transparent, elastic polymers with UV fluorescence form durable links, while low-grade mixtures are prone to brittle fractures and early slippage.

Hand Hygiene

The main cause of failure is re-contamination with oils and silicones transferred from the master’s fingers. The double-wash and alcohol-disinfection protocol completely eliminates this risk.

Placement Angle

The optimal 30° angle ensures balanced load distribution. When the angle exceeds 45–50°, the lower part of the strand sags, creating localized tension and progressive detachment.

Strand Geometry

The “horseshoe” selection shape minimizes stress points. Sharp or irregular angles, on the other hand, create weak zones that quickly fail under mechanical load.

Aftercare

Only the first 12–24 hours are critical, as the polymer interface stabilizes during this period. Later, aftercare becomes a supportive factor—it helps reduce mechanical wear but does not determine bond strength.

Comparison of Methods

Unlike classical or ultrasonic techniques, the InvisiCaps method standardizes key parameters (T–t–p, 30° angle, strand mass ratio), providing predictable and consistent results.

Therefore, capsule detachment should not be considered accidental or a result of client negligence, but rather a consequence of deviations in controllable parameters. The standardization embedded in the **InvisiCaps method** allows for a significant reduction in failure rates and ensures high reproducibility of the procedure.

LIMITATIONS OF STUDY

This study has several limitations that should be taken into account when interpreting the results:

– Data Source

The analysis is based primarily on salon practice logs and case observations. Laboratory verification of polymer characteristics (e.g., via scanning electron microscopy, differential scanning calorimetry, or spectroscopy) was not performed.

– Hair Variability

Hair diameter and structure may vary significantly depending on ethnicity and age. These parameters were not stratified, which limits generalization.

– Aftercare Reporting

Information on hair care practices was collected through client self-reports, which may introduce subjectivity or inaccuracies.

– Operator Factor

The study did not include inter-operator comparison. All procedures were conducted within one trained practice, eliminating technique variation but limiting broader reproducibility.

– Capsule Loss Norm

The acceptable capsule loss rate was defined as ≤10 over 3 months. This standard reflects premium-segment expectations and may differ from those in the mass market.

CONCLUSIONS

Capsule retention in hair extension procedures functions as an integrated system of interdependent factors: polymer chemistry, surface cleanliness, placement angle, and strand geometry. The main controllable risks include re-contamination from the master's hands, insufficient tool heating, and imbalance between donor and client strand masses.

The optimal placement angle (≈30°) and the correct horseshoe-shaped strand selection significantly reduce the likelihood of premature slippage or mechanical detachment.

The **InvisiCaps method**, based on the standardization of T–t–p parameters, placement geometry, and strand mass ratio, demonstrates higher stability and aesthetic quality compared with classical Italian, ultrasonic, and cold adhesive techniques.

Therefore, the introduction of InvisiCaps can be regarded as a new premium standard in hair extension practice, providing reproducibility, minimized risk, and long-term result preservation.

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