Date of first submission	2026-05-30
Date of acceptance of article for publication after review	2026-07-25
Date of publication/publication	2026-07-25

Technological Innovations in Permanent Makeup: Contemporary Approaches to Pigmentation, Skin Interaction and Procedure Stability

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Abstract. Background: Technological development in permanent makeup (PMU) has progressed across three interdependent domains: pigment chemistry, delivery instrumentation, and procedural architecture. Each domain has advanced independently in the published literature and in commercial practice, yet their clinical effects are inseparable—pigment stability, tissue interaction, and long-term outcome quality are each determined by the interaction of all three. Objective: This paper evaluates contemporary technological developments in PMU across pigment chemistry, needle technology, and machine parameters, examining how each contributes to procedure stability and long-term aesthetic outcomes in permanent lip makeup specifically. Methods: The analysis integrates peer-reviewed findings in dermatology, pigment science, and cosmetic tattooing technology with the author's clinical methodology, developed through more than eleven years of specialized practice and over 2,000 lip procedures. Results: The most significant contemporary innovation in PMU is not any single technological development but the integration of pigment chemistry knowledge, needle-specific tissue interaction profiles, and voltage-governed machine parameters into a unified, parameter-defined procedural system. Conclusion: Procedure stability and long-term outcome quality in PMU are achievable only when technological variables are governed by a systematic, clinically-grounded methodology rather than managed empirically.

Keywords: permanent makeup, pigment chemistry, needle technology, rotary machine, procedure stability, skin interaction, PMU innovation, lip micropigmentation.

Introduction

The technological landscape of permanent makeup has undergone substantial transformation over the past two decades. The field's earliest implementations relied on manual tattooing instruments and rudimentary pigment formulations designed for decorative body art rather than for the specific optical and biological demands of facial cosmetic application. Contemporary PMU practice is conducted with purpose-designed rotary machines capable of electronic speed and voltage control, cartridge-based needle systems engineered for specific tissue interaction profiles, and pigment formulations developed in awareness of the dermal optical environment and the regulatory requirements governing long-term biocompatibility. Each of these technological advances has expanded the range of outcomes achievable by a skilled practitioner but none has resolved the fundamental challenge of permanent lip makeup: that achieving a stable, predictable, natural-looking healed result requires the correct integration of all three domains simultaneously [10, 17].

The peer-reviewed literature on PMU technology is distributed across these three domains without a unifying clinical framework. Pigment chemistry research has advanced understanding of colorant stability, contaminant profiles, and biocompatibility risks [1, 4, 8], but has not established the technique parameters required to exploit this knowledge clinically. Instrumentation research has characterized needle geometry and machine mechanics [12, 17], but has not defined how specific configurations should be matched to anatomical zones and

ISSN: 2787-9364

outcome targets. Regulatory developments have restricted certain pigment classes and imposed quality standards on PMU materials [5, 6], but have not addressed the procedural architecture that governs how compliant materials are used.

The clinical consequence of this fragmentation is a field in which technological capability has consistently outpaced the systematic knowledge required to apply it. Practitioners have access to better machines, better needles, and better pigments than at any prior point in the field's history and yet the complication and dissatisfaction literature continues to document outcomes directly attributable to technique failure: tonal shift, over-saturation, border migration, and gradient absence [7, 18]. The problem is not a technology deficit; it is a clinical integration deficit.

This paper argues that the most significant contemporary innovation in PMU is the development of a procedural architecture that integrates technological variables pigment chemistry, needle configuration, and machine parameters into a unified, parameter-governed system. Drawing on the author's "From Nude to Lipstick" methodology [24] and the relevant peer-reviewed literature, it evaluates contemporary PMU technologies across the three domains and demonstrates how their clinical potential is realized only when they are governed by a systematic, evidence-consistent procedural framework. The argument is illustrated through reference to permanent lip makeup as the most technically demanding and aesthetically significant application domain within the field.

Literature Review

Pigment Chemistry: Advances, Limitations, and Clinical Implications. The chemistry of PMU pigments has been the most extensively studied technological domain in the peer-reviewed literature, driven primarily by safety concerns rather than performance optimization. Andreou et al. provide the foundational safety analysis of PMU colorants, documenting the distinctions between inorganic iron oxide pigments, which offer high photostability and low allergenicity and organic pigments, which provide a broader color range but are associated with UV-induced photodegradation and a higher allergic contact dermatitis risk [1]. Rigali et al. extend this analysis specifically to PMU formulations, identifying the pigment classes associated with the highest rates of allergic sensitization and noting that the molecular weight and chemical structure of a pigment are primary determinants of its immunogenic potential [20].

Colboc et al. advance understanding of pigment behavior at the chemical microenvironment level, employing synchrotron radiation to characterize ink composition in reactive skin and demonstrating that dermal tissue actively modifies implanted pigment through pH effects, cellular encapsulation, and oxidative processes [4]. This finding has direct clinical implications: the color a pigment exhibits in the bottle is not the color it will exhibit in the dermis, and the direction and magnitude of in-vivo color modification are functions of both the pigment's chemical properties and the tissue environment into which it is placed. Hering et al. provide a methodological framework for studying these interactions through their TatS in vitro skin model, establishing a research platform capable of evaluating pigment behavior in tissue-equivalent conditions [11].

The regulatory environment has introduced a further technology-shaping variable. DeBiasio et al. analyze the implications of the European Union's restriction of certain pigment classes for North American PMU practice, noting that formulation constraints are progressively narrowing the available palette [6]. Ćwieląg-Drabek et al. document ongoing heavy metal contamination in commercially available PMU inks despite existing standards [5], and Fels et al. provide a regulatory evaluation establishing arsenic, cadmium, and polycyclic aromatic hydrocarbons as persistent concerns in the ink supply chain [8]. Together, these analyses establish that pigment selection in contemporary PMU is not merely a color decision but a regulatory and biocompatibility decision with direct implications for long-term outcome stability.

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Needle Technology and Skin Interaction Mechanics. Needle technology represents the interface between the practitioner's procedural intent and the tissue's biological response. Pachten et al. provide the most comprehensive technical characterization of PMU needle configurations in the peer-reviewed literature, documenting the geometry of round liners, round shaders, magnums, and their derivatives in terms of needle count, grouping pattern, and the mechanical interaction profiles these geometries produce in tissue [17]. Their analysis establishes that needle configuration is not a preference variable but a technical specification with predictable consequences for pigment deposition depth, lateral spread, and tissue trauma.

Hvas and Serup examine the relationship between needle parameters and pigment distribution in cosmetic tattooing, demonstrating that hand speed, needle penetration depth, and voltage each independently modulate the volume and distribution of pigment deposited per unit area [12]. Marwah et al. establish analogous principles in microblading, demonstrating that blade geometry and applied pressure determine not only pigment depth but the width of the deposition track with direct relevance to rotary machine-based lip procedures, where the equivalent variables are needle configuration and machine voltage [15].

The clinical significance of needle selection is most apparent at the anatomically sensitive vermilion border. Tomita et al. document complications specific to cosmetic tattoo procedures at high-visibility facial sites, identifying over-penetration and pigment migration as the primary technique-attributable failure modes [23]. Kerure et al. note that micropigmentation practitioners widely acknowledge the need for anatomically differentiated technique but rarely formalize this differentiation in written protocols leaving needle selection as a largely intuitive decision with outcome variability as its predictable consequence [14].

Machine Technology: Rotary Systems, Voltage Control, and Procedural Precision. The transition from coil machines to rotary systems represents the most consequential technological shift in PMU delivery instrumentation over the past two decades. Pachten reviews the mechanical properties of rotary machines, noting that electronic speed control and consistent needle throw produce a more uniform tissue interaction than coil-driven mechanisms, reducing per-stroke variability and enabling the reproducible voltage settings that parameter-governed technique protocols require [16]. Contemporary professional rotary machines provide voltage adjustment in increments of 0.1V across a range typically spanning 3.0–12.0V, enabling the fine-grained parameter specification that differentiates base layer implantation (5.5–6.5V) from gradient construction (6.5–7.5V) and selective saturation (5.0–6.0V, reduced speed) as defined in the author's methodology [24].

Ghafari et al. document the evolution of PMU instrumentation, noting that rotary machines now dominate professional practice across all facial PMU sites [10]. Argobi et al. and Shishak and Kuthial both identify machine misuse, inappropriate speed settings, incorrect voltage for tissue type, and non-standard needle configurations as primary mechanism-level predictors of adverse outcomes in cosmetic tattooing, reinforcing that advanced machine technology does not independently improve outcomes; it requires parameter governance to do so [2, 21].

The Integration Gap: Technology Without Procedural Architecture. The central technological limitation documented across the PMU literature is not any deficiency in individual components, pigment formulations, needle designs, and rotary machines have each advanced substantially, but the absence of a clinical framework that integrates these components into a governed, reproducible procedural system. Chalarca-Cañas et al. document the full histopathological range of tattoo-related complications and identify technique-tissue mismatch as a primary etiology a diagnosis that implies not merely incorrect execution of a defined protocol but the absence of a protocol calibrated to the relevant tissue characteristics [3]. Ibraheim et al. and Suleman et al. report granulomatous reactions in PMU clients whose procedures used commercially available, regulatory-compliant pigments establishing that

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material compliance does not prevent clinical failure when implantation parameters are not governed by tissue-appropriate protocols [13, 22].

Pióro et al. and Pióro et al. demonstrate the downstream consequences of this integration gap: unsatisfactory PMU outcomes requiring removal, with measurable quality-of-life consequences and removal difficulty that varies with the pigment density and depth of the initial procedure [18, 19]. Geisler et al. confirm that laser removal efficacy is substantially constrained by the technical variables of the original procedure, establishing a direct line of clinical consequence from initial parameter selection to long-term correctability [9].

Methods

This paper analyzes PMU technological innovation through a clinically grounded framework derived from the author's "From Nude to Lipstick" methodology [24]. That methodology constitutes a specific instance of the technological integration this paper argues for: it defines, for each procedural stage, the precise needle configuration, voltage range, machine speed, and pigment class appropriate to the tissue zone and outcome target being addressed. The methodology thereby functions as a working example of what PMU technological integration looks like at the clinical level, making it the appropriate primary comparator for an evaluation of whether and how contemporary PMU technologies, taken individually or in combination, are capable of producing stable, predictable outcomes.

The three technological domains addressed in this analysis, pigment chemistry, needle technology, and machine parameters were selected because they correspond to the three primary variables that the author's clinical experience identified as determinative of procedure stability and long-term outcome quality. Each domain is evaluated against two criteria: first, the degree to which current scientific understanding of that domain's properties is adequate to support parameter-governed clinical decision-making; and second, the degree to which conventional PMU practice operationalizes that understanding in defined procedural protocols.

The peer-reviewed literature provides the evidence base for the first criterion in each domain. The author's methodology, developed through more than eleven years of specialized practice and over 2,000 lip procedures, provides the primary evidence base for the second. The comparative assessment presented in the Findings section identifies, for each technological domain, the gap between what the science supports and what conventional practice implements—and demonstrates how the author's methodological framework closes that gap through specific parameter definitions and procedural sequences.

Results

Needle Configuration as a Clinical Precision Variable. The first principal finding is that needle technology has advanced to a degree of specificity that enables, but does not automatically produce, anatomy-matched implantation precision. Table 1 presents the needle configurations deployed within the author's methodology, their tissue interaction profiles as established in the literature, and their specific functional roles across the three-layer implantation architecture.

Table 1. Needle Configuration, Tissue Interaction Profile, and Methodological Role in Permanent Lip Makeup

Needle Type	Configuration	Tissue Interaction Profile	PMU Application Zone	Role in "From Nude to Lipstick"
Round Liner (RL)	1003RL	Precision deposition; minimal lateral spread	Base layer; vermilion border; Cupid's bow	Base coverage (5.5–6.5V); border zone definition; low-density gradient edge
Round Shader	1205RS	Broader deposition;	Gradient construction	Directional gradient layer (6.5–7.5V); center

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Needle Type	Configuration	Tissue Interaction Profile	PMU Application Zone	Role in "From Nude to Lipstick"
(RS)		moderate lateral diffusion	(center-to-border)	saturation building
Round Magnum (RM/MG)	7RM / 7MG	Wide coverage; high pigment volume per pass	Central saturation zone only	Selective saturation layer (5.0–6.0V, reduced speed); full-density central zone

Source: Tissue interaction profiles informed by Pachten et al. and Hvas & Serup [12, 17]. Voltage and application parameters from Vasylchenko [24].

The three-needle architecture 1003RL for precision base and border work, 1205RS for gradient construction, and 7RM/7MG for selective central saturation, represents a deliberate technology-anatomy matching strategy. Each needle is assigned to the specific tissue zone and procedural function for which its geometry is optimized. This is the operational expression of the principle established by Pachten et al.: that needle configuration is a technical specification with predictable tissue consequences, not a practitioner preference [17].

Pigment Chemistry Classes and Protocol-Level Management. The second principal finding concerns the relationship between pigment chemistry knowledge and clinical protocol design. Table 2 presents the primary pigment classes used in permanent lip makeup, their stability and risk profiles as documented in the literature, and the technique-level mitigations defined within the author's methodology.

Table 2. Pigment Chemistry Classes, Stability Profiles, and Protocol-Level Mitigation in PMU

Pigment Class	Common PMU Use	Long-Term Color Stability	Key Risk Profile	Technique-Level Mitigation
Iron oxide (inorganic)	Lip blush, nude shades	High; resistant to photodegradation	Warm-to-cool shift on hyperpigmented tissue	Neutralization protocol before target shade application
Organic pigments (azo, phthalocyanine)	Vivid lip colors	Moderate; UV-sensitive, prone to tonal shift	Photodegradation; color migration; allergenicity	Layered low-density implantation; reduced trauma per pass
Warm modifier pigments (Caramel, Terracotta, Evenflo)	Neutralization base layer	Intermediate; functions as chromatic base	Over-application shifts final color orange	Phototype-stratified modifier selection; single-pass base application only

Source: Stability and risk data informed by Andreou et al., Rigali et al., Colboc et al., and Fels et al. [1, 4, 8, 20]. Mitigation protocols from Vasylchenko [24].

The critical finding embedded in Table 2 is that the most commonly cited pigment-chemistry risk in lip PMU the warm-to-cool tonal shift produced by iron oxide pigments on hyperpigmented tissue is not a pigment quality failure but a protocol design failure. The pigment performs exactly as its chemistry predicts; the clinical error is the absence of a

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neutralization step that accounts for the predictable optical interaction between the pigment and the tissue. Technology literacy, knowing what the pigment will do, must be paired with protocol architecture to produce the clinical response (See Figure 1).

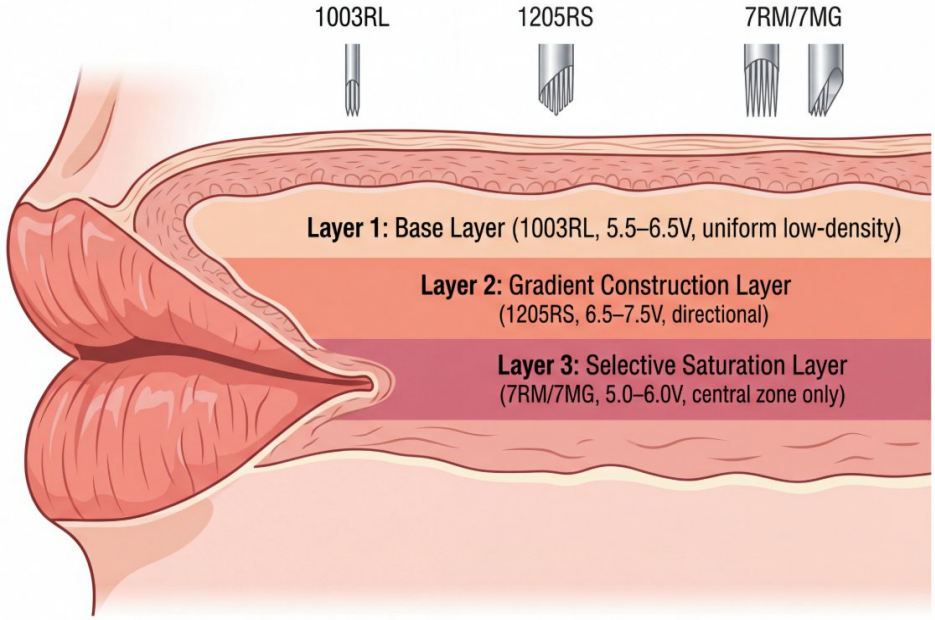

Figure 1. From Nude to Lipstick Three-Layer Lip Tattoo Implantation Architecture
Source: author's development

Discussion

The Integration Imperative: Why Technology Alone Is Insufficient. The argument of this paper is that the most significant contemporary development in permanent makeup technology is not any individual advancement in pigment chemistry, needle design, or machine engineering all of which have been substantial, but the emergence of a clinical framework capable of integrating these advances into a governed procedural system. This argument reflects a broader principle in clinical technology: that the value of a technological capability is determined not by the capability itself but by the degree to which clinical practice is structured to exploit it.

The PMU literature provides abundant evidence that this integration has not been achieved in conventional practice. Dodig et al. and Chalarca-Cañas et al. document complication profiles attributable to technique-tissue mismatch a diagnosis that presupposes the existence of a correct technique-tissue matching framework that practitioners are failing to apply [3, 7]. The failure is not primarily technological; it is architectural. Practitioners have access to the correct needles, machines, and pigments; what many lack is a defined, transmissible protocol for deploying them in the correct combination, at the correct parameters, in the correct sequence.

The author's "From Nude to Lipstick" methodology demonstrates what such a protocol looks like in practice. Its nine-step non-negotiable procedural sequence defines not only what to do but in what order, with what instruments, at what parameters, and with what execution criteria at each stage [24]. The sequence is non-negotiable not as a matter of rigidity but because the clinical dependencies between steps are real: the neutralization pass must precede the gradient construction layer because the warm base it establishes is the chromatic foundation on which the target shade is implanted. The border zone parameters must be applied before the central saturation layer because over-saturation of the center after the border is defined risks mechanical trauma that compromises the gradient edge. These are not style preferences; they are technological dependencies made explicit.

ISSN: 2787-9364

Voltage Governance as a Safety and Quality Variable. Among the machine technology variables the author's methodology operationalizes, voltage governance deserves specific attention as both a quality and safety variable. The voltage delivered by a rotary PMU machine determines the force with which the needle penetrates tissue on each stroke, directly governing implantation depth, pigment volume per pass, and the degree of tissue trauma generated per unit area treated. Pachten et al. establish this relationship in their equipment review [17]; its clinical consequences are documented by Ibraheim et al. and Suleman et al., who identify over-penetration and high pigment density as primary risk factors for granulomatous inflammation [13, 22].

The author's methodology deploys voltage as a precision variable rather than a fixed setting, defining specific ranges for each procedural layer: 5.5–6.5V for the base layer, 6.5–7.5V for gradient construction, and 5.0–6.0V with reduced machine speed for the selective saturation layer [24]. These ranges reflect the tissue requirements of each layer: the base layer requires sufficient penetration for uniform coverage without saturation; the gradient construction layer requires higher force for directional depth-building; the saturation layer requires depth without the high speed that would produce over-penetration. This voltage architecture is only achievable on contemporary rotary machines with electronic voltage control, it represents a direct translation of machine technological capability into clinical parameter governance.

The Regulatory Dimension of Technological Innovation. The regulatory environment governing PMU pigments constitutes a technological constraint with direct procedural implications. DeBiasio et al. document the impact of the European Union's restriction of specific pigment classes on the available formulation palette, reductions that require practitioners to adapt pigment selection strategies as the commercial supply changes [6]. Ćwieląg-Drabek et al. establish that heavy metal contamination remains a documented risk in commercially available inks [5], and Fels et al. identify the contaminant classes of greatest regulatory concern [8].

These regulatory developments create a dynamic technological environment in which pigment selection protocols cannot be fixed indefinitely; they must be revisited as formulations change and regulatory standards evolve. A methodology built around generic pigment class properties rather than specific commercial products, as the author's neutralization protocol is, defining modifier type by chemical function (warm-toned modifier pigment) rather than brand name alone is inherently more robust to this regulatory dynamism. This is a design feature that reflects awareness of the regulatory landscape documented by DeBiasio et al. and Ćwieląg-Drabek et al. [5, 6].

Procedure Stability as a Composite Technological Outcome. The concept of "procedure stability" in PMU refers to the degree to which a healed outcome remains consistent with the immediately post-procedure result over time, resisting the tonal shift, density loss, and border degradation that characterize unstable implantations. The literature establishes that stability is a composite outcome determined by the interaction of pigment chemistry [1, 4], implantation depth and density [3, 11], and tissue response [7, 13]. No single technological variable governs stability independently.

This composite nature of stability is what makes an integrated procedural framework, rather than optimized individual components the appropriate technological response. Selecting a photostable pigment does not prevent tonal shift if the implantation density is insufficient for long-term retention. Correct needle selection does not prevent border degradation if machine voltage is inconsistent. The layered implantation architecture of the author's methodology addresses stability at each level simultaneously: the base layer establishes uniform low-density coverage that resists patchy healing; the gradient construction layer's directional protocol produces gradient stability because the edge zone remains low-density throughout; and the selective saturation layer achieves full central density without the over-penetration that accelerates pigment breakdown [24]. Stability is the emergent property of correct technological integration, not the product of any single component.

ISSN: 2787-9364

Implications for the Field: Technology, Training, and Standardization. The technological integration argument of this paper has direct implications for how PMU is taught and how professional competency is defined. Argobi et al. identify training adequacy as a primary predictor of PMU outcome quality, and Shishak and Kuthial establish that inadequate training is the principal mechanism of microblading complications [2, 21]. The equivalent principle holds for lip PMU: a practitioner who has been trained in needle selection, voltage governance, and pigment chemistry independently, but not in their integration within a governed procedural system, possesses technological knowledge without the clinical architecture to deploy it reliably (See Figure 2).

The transmissibility of a technology-integrated methodology is therefore a central professional value. The author's "From Nude to Lipstick" methodology has been formalized in a published manual and implemented in structured training programs precisely because its value as a clinical system depends on its capacity to be learned, assessed, and applied by practitioners beyond its originator [24]. Kim and Kwon document the sustained growth in PMU procedural demand, making the quality of technology-integrated training an increasingly significant determinant of field-wide outcomes (See Figure 3). The gap between what contemporary PMU technology makes achievable and what current training standards reliably produce is the primary unresolved challenge for the field's next stage of development.

Figure 2. PMU Lip Healing Comparison: Conventional vs Layered Low-Voltage Methodology
Source: author's development

ISSN: 2787-9364

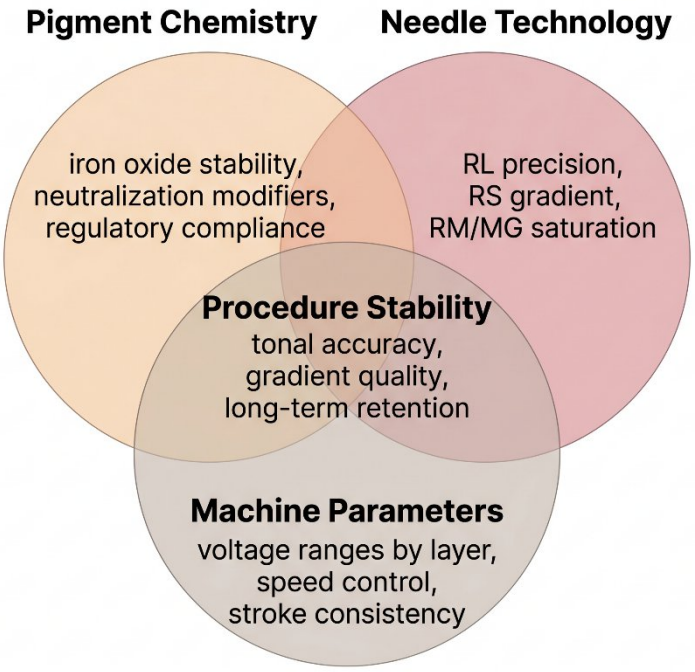

Figure 3. Technology Integration
Source: author's development

Conclusions

This paper has argued that technological innovation in permanent makeup has advanced sufficiently across pigment chemistry, needle design, and machine engineering to make stable, predictable, high-quality outcomes achievable, but that this potential is realized only when technological variables are integrated into a governed, parameter-defined procedural system. The peer-reviewed literature documents both the capabilities of individual technologies and the failure modes that result when those technologies are deployed without a clinical architecture governing their interaction.

The author's "From Nude to Lipstick" methodology demonstrates that such an architecture is achievable at the clinical level: by defining specific needle configurations, voltage ranges, pigment classes, and procedural sequences for each stage of the permanent lip makeup procedure, it converts technological capability into governed clinical practice. The three-needle architecture matched to anatomical zones, the voltage-differentiated three-layer implantation system, the phototype-stratified neutralization protocol, and the non-negotiable nine-step procedural sequence together constitute a working model of what PMU technological integration looks like in clinical application.

The broader implication for the field is that technological advancement in PMU requires a corresponding advancement in the clinical frameworks through which technology is applied. The regulatory tightening documented by DeBiasio et al. and Ćwieląg-Drabek et al., the complication profiles documented by Dodig et al. and Ibraheim et al., and the quality-of-life consequences documented by Pióro et al. all point to the same conclusion: PMU's technological maturity has outpaced its procedural standardization, and closing this gap is the defining clinical challenge and opportunity for the field in its current stage of development.

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