Global Disparities in Mohs Micrographic Surgery: the Privileging Gap and a Type I/II/III Framework for Implementation

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Abstract

Mohs micrographic surgery (MMS) achieves the lowest recurrence rates for high-risk skin cancer through complete, intraoperative margin assessment: thin tissue layers are excised, mapped, and examined as horizontal frozen sections, and the operating surgeon selectively re-excises only areas of residual tumor—a closed excision–interpretation loop that maximizes oncologic control and tissue preservation. Despite established efficacy across multiple cutaneous malignancies, global adoption remains uneven. This review argues that the principal barrier is often not technical capacity but credentialing architecture: in many settings, dermatologic surgeons possess the skills for frozen-section interpretation yet lack institutional authorization to independently render intraoperative diagnoses—a privileging gap. We propose a heuristic three-type framework—Type I (independent diagnosis), Type II (collaborative diagnosis), and Type III (referral networks)—with the transition from collaborative to independent practice framed as a directional hypothesis with a defined testing agenda. The review further examines how MMS in the United States evolved from contested interpretive authority to formalized credentialing, and considers how this history may inform implementation in China and other constrained settings. A tiered pathway is proposed: tertiary centers provide full MMS, regional hospitals adopt staged excision approaches, and community clinicians emphasize recognition and referral. The central challenge is institutional adaptation: preserving complete margin assessment while aligning technical capability with diagnostic authority.

Keywords: Mohs micrographic surgery; credentialing; frozen section; dermatologic surgery; skin neoplasms; tissue conservation; global implementation

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Introduction

From the clinic to the page: why this review matters

Mohs micrographic surgery (MMS) is founded on a principle that distinguishes it from most other forms of oncologic surgery: margin status is not assumed on the basis of empiric safety margins, but verified intraoperatively through complete microscopic examination of the excised tissue. In this sense, MMS is defined not simply by staged excision, but by a closed excision–interpretation loop in which the surgeon identifies residual tumor, correlates histopathologic findings with the surgical map, and re-excises only where tumor persists. This process provides a level of precision that has made MMS the gold standard for many high-risk nonmelanoma skin cancers.

Over the past two decades, this precision has translated into consistently favorable oncologic outcomes. Five-year recurrence rates for primary basal cell carcinoma (BCC) treated with MMS are typically below 1%, outcomes that are difficult to match with standard excision, curettage-based approaches, or radiation therapy in comparable high-risk settings[1]. Yet despite its established efficacy, the implementation of MMS remains uneven worldwide. In discussions with dermatologists and trainees in China and other parts of Asia, several recurring questions arise: Is MMS really necessary for every case? Can it be performed effectively without a dedicated Mohs laboratory? Why should institutions invest in MMS when dermatopathology resources are already limited?

These are not merely practical questions; they reflect a broader structural tension. MMS is simultaneously a mature, evidence-based solution and an incompletely implemented system of care. The epidemiologic context underscores the importance of these questions. Skin cancer is the most common malignancy worldwide, and its burden continues to rise. Rogers *et al.*[2] estimated that more than 5.4 million keratinocyte carcinomas were treated in the United States in 2012 alone. Globally, the age-standardized incidence rate (ASIR) rose 1.94% annually from 1990 to 2021, reaching 6.64 million new cases in 2021[3], with East Asia showing one of the steepest increases (estimated annual percentage change [EAPC] = 4.42%), driven primarily by BCC and squamous cell carcinoma (SCC)[3]. Modeling suggests this burden will continue to grow through 2050, particularly in aging populations[4]. In China, national analyses describe a regionally heterogeneous but concerning picture: skin cancer burden is concentrated in more economically developed regions, while lower case volumes in rural areas likely reflect underdiagnosis rather than truly lower incidence[5,6].

A review of MMS is therefore timely not only because of its clinical value, but also because of the widening gap between growing need and uneven institutional capacity. Any contemporary review should address not only principles, indications, and outcomes, but also the structural conditions that determine whether this technique can be implemented in real-world practice.

A brief history: from chemosurgery to micrographic surgery

The origins of MMS date to the 1930s, when Frederic E. Mohs at the University of Wisconsin developed a technique that combined *in vivo* chemical fixation with staged excision and complete microscopic margin control. In his seminal 1941 paper[7] in the *Archives of Surgery*, he described this approach as "chemosurgery." Although the terminology was later abandoned, the underlying concept proved enduring: the extent of cancer surgery should be determined by microscopic evidence rather than surgical estimation alone.

The modern form of MMS emerged in the 1970s, when Theodore Tromovitch and Samuel Stegman[8] introduced the fresh-tissue technique using frozen-section processing. This modification eliminated the need for zinc chloride fixation and made same-day margin-controlled surgery feasible within routine dermatologic practice. The fresh-tissue technique transformed MMS from a specialized, chemically complex procedure into a practical clinical workflow. Over time, structured fellowship training, professional standardization, and the development of the American College of Mohs Surgery (ACMS) helped establish MMS as a recognized standard of care for selected high-risk cutaneous malignancies.

However, historical development has not been uniform

across countries. In the United States, MMS expanded within a healthcare environment that supported its adoption: specialized training pathways, access to frozen-section laboratories, reimbursement mechanisms, and emphasis on tissue preservation. In many other settings, including Chinese mainland, these enabling conditions were either incomplete or absent. As Deng[9] noted, the technique was introduced largely through academic exchange and individual initiative rather than coordinated institutional adoption. This mode of introduction has had lasting consequences: advanced tertiary centers may provide sophisticated MMS-related care, while many institutions continue to manage suspicious lesions through standard excision with delayed permanent-section pathology. The central gap is institutional rather than technological—major tertiary hospitals often possess frozen-section capabilities comparable to Western centers, but the credentialing framework generally does not authorize dermatologic surgeons to independently sign out frozen-section diagnoses.

The MMS paradigm: certainty in an uncertain field

At its core, MMS represents a distinct surgical and diagnostic paradigm. Standard excision relies on probabilistic reasoning: a margin is selected that is considered likely to encompass subclinical extension, with confirmation deferred until permanent-section pathology. MMS changes this sequence fundamentally: tissue is removed in thin, mapped layers and examined using horizontal frozen sections that permit assessment of 100% of the peripheral and deep margins. The surgeon correlates histologic findings with the operative map and re-excises only areas of residual tumor. Reconstruction proceeds only after margin clearance is confirmed.

This paradigm depends on expertise in both excision and histopathologic interpretation. In the United States, this dual role is embedded within fellowship training and recognized through institutional privileging. In China and many other countries, complete margin assessment may still be achievable, but often only through collaboration between dermatologic surgeons and pathologists because independent intraoperative interpretation by the surgeon is not formally authorized. This distinction should not be mistaken for a deficit in technical capability: in many settings, dermatologic surgeons with advanced training possess the practical skills required for frozen-section interpretation. The limiting factor is often institutional authorization rather than professional competence. We refer to this discrepancy as the "privileging gap": a situation in which the technical ability to perform the diagnostic component of MMS exists, but the legal or institutional authority to independently render frozen-section diagnoses does not.

MMS is also resource-intensive, requiring laboratory infrastructure, trained personnel, and time for iterative excision and interpretation. These demands have fueled debates regarding overutilization for low-risk tumors, cost-effectiveness in low-resource systems, and operator dependence. This review does not dismiss these controversies but argues that they should be situated within a broader implementation framework. The central international question is not simply whether MMS is effective in the abstract, but how it can be implemented when technical capability exists but institutional authority is incomplete.

Scope of this review

This review examines MMS across seven interrelated dimensions: its fundamental principles, patient selection and appropriate use criteria, technical execution, the evidence base and clinical outcomes, global implementation patterns, innovations and future directions, and conclusions.

Our central thesis is that the principal barrier to broader global implementation of MMS is often not technical incapacity, but variation in credentialing systems. We introduce a heuristic three-type framework: Type I (independent diagnosis), Type II (collaborative diagnosis), and Type III (referral-based networks). Type I and Type II share the technical core of complete *en face* margin assessment, Mohs mapping, and an intraoperative excision–interpretation feedback loop; they differ only in the locus of diagnostic accountability. The framework is a heuristic typology, not an evidence-based hierarchy: in the absence of direct comparative studies, the proposed transition from collaborative to independent practice is a directional hypothesis with a defined testing agenda (described in the roadmap below).

The typology classifies how margin-controlled surgery is delivered; it does not classify skin cancer surgery in general. Standard excision—with vertical bread-loaf sectioning that samples only a fraction of the surgical margin—lies outside the framework altogether. Within the framework, this background practice is what Type III referral networks triage: the task at the community level is to ensure that high-risk lesions are recognized and referred for margin-controlled surgery (described below). Comparisons between Mohs surgery and standard excision are therefore treated as evidence of technical efficacy—establishing the value of the shared technical core—and not as evidence bearing on the Type I–II distinction. Nor are Type II arrangements confined to systems with a formal privileging gap: staged excision with complete margin assessment and pathology sign-out ("slow Mohs") and margin-controlled excision with pathologist-interpreted frozen sections are in routine use in the United States as well, illustrating that collaborative interpretation is not solely a response to credentialing restriction.

The objective of this review is not to prescribe a single universal model, but to clarify how the defining principle of MMS—complete margin assessment linked to immediate surgical decision-making—can be maintained while adapting its delivery to different regulatory, institutional, and resource environments.

Fundamental principles

The philosophical divide: margin verification vs. estimated excision

Standard excision relies on estimated tumor clearance: the surgeon selects a clinically appropriate margin and depends on postoperative histopathologic sampling to determine adequacy. MMS, by contrast, is based on direct margin verification—examining the entire peripheral and deep surgical margin intraoperatively and directing further excision only to sites where residual tumor is identified. This distinction matters because cutaneous malignancies often extend beyond visible borders, particularly in aggressive histologic subtypes and tumors along embryonic fusion planes. Recurrence data after standard excision illustrate the limitations of estimated margins[10]. MMS converts the operative logic from "remove and hope" to "verify, then re-excise selectively."

This logic was originally designed as an integrated workflow in which the same physician both excises the tissue and interprets the frozen sections. When the excision–interpretation loop is unified, clinical findings, tissue handling, histopathology, and surgical decision-making remain tightly linked. When that loop is divided across practitioners or departments, the process can still function, but additional vulnerabilities are introduced—implications discussed throughout this review.

Technical foundations: horizontal processing and complete margin assessment

The effectiveness of MMS depends on several interdependent steps, each contributing to accurate identification of residual tumor. The specimen is excised with an approximately 45-degree bevel to facilitate flattening for horizontal sectioning, rapidly frozen and sectioned at 4–6 μm, and stained with hematoxylin and eosin. A defining feature is the use of horizontal (*en face*) sectioning rather than vertical bread-loaf sections, which samples only a small proportion of the true margin[11]. Horizontal sectioning is designed to display the entire peripheral and deep margin in one plane, converting margin evaluation from a sampling strategy into a near-complete examination strategy. Accurate tissue orientation—preserved through nicks, notches, and dye marking—is essential for reliable stage-to-stage correlation; errors in orientation, flattening, or labeling can create false-negative or misleading results. The diagnostic quality of frozen sections depends on multiple factors, including freezing rate, cryostat temperature, section thickness, and staining consistency, and artifacts such as ice crystal formation, folding, and chatter must be recognized by the interpreter. The practical implications of these technical requirements for collaborative and institutional models are discussed below.

Why standard MMS is irreplaceable: the surgeon's advantage

The technical steps described above can, in principle, be distributed across a collaborative team. However, important advantages arise when the same physician performs

both the excision and the histopathologic interpretation. These advantages are difficult to reproduce fully when the excision–interpretation loop is divided between surgeon and pathologist.

First, integration strengthens clinicopathologic correlation. The Mohs surgeon who created the defect knows where the tumor appeared clinically deepest, where the margins were most ambiguous, and which portions of the tissue were most difficult to orient or flatten. This direct correlation between operative findings and microscopic interpretation is diagnostically valuable and cannot be completely replaced by written notes or verbal handoff.

Second, integration improves artifact recognition. Frozen sections are inherently prone to preparation artifacts, including folds, tears, floaters, and freezing-related distortion. The surgeon who works repeatedly with the same laboratory process develops familiarity with recurring technical artifacts and their appearance, which may improve distinction between artifact and residual tumor. In contrast, an interpreter who is less familiar with the technical patterns of a specific Mohs workflow may face greater uncertainty.

Third, integration facilitates real-time surgical decision-making. MMS is an iterative procedure in which each stage determines the next. The location and extent of residual tumor dictate whether another stage is required, where re-excision should occur, and how much additional tissue should be removed. When the surgeon interprets the slides directly, this feedback loop can proceed rapidly. When interpretation is delayed or separated from the operative process, efficiency declines, tissue edema may increase, and the patient experience may worsen.

Fourth, integration may improve recognition of incidental or discordant findings. Complete margin assessment occasionally reveals pathology unrelated to the index lesion. Cooper *et al.*[12], in a systematic review of 29 studies involving 680 patients, found that 91.3% of incidental findings identified during MMS required additional intervention. Cohen *et al.*[13] reported recurrent ductal carcinoma *in situ* detected incidentally during MMS for superficial BCC of the nipple. Recognition of such abnormalities often depends on vigilance for histologic patterns that do not fit the presumed diagnosis, which may be enhanced when the interpreter possesses direct clinical context.

Fifth, integration supports full-chain quality control. The quality of MMS is determined not only by slide interpretation, but also by the technical chain preceding it, including orientation, freezing, embedding, sectioning, and staining. When the operating surgeon is directly engaged with this workflow, quality control spans the entire process from excision to interpretation. In collaborative systems, by contrast, upstream technical quality may depend on personnel who are not specifically trained in MMS, and deficiencies in specimen preparation may propagate downstream as diagnostic uncertainty. Reported analyses suggest that technical and interpretive factors together account for a substantial proportion of local recurrences after MMS[14,15], and acceptance of poor-quality sections has been identified as a modifiable contributor to treatment failure[16]. These are not reading errors alone—they are chain-of-custody failures that an integrated practitioner could prevent.

These advantages help explain why formal Mohs training emphasizes competence in both surgery and histopathology, and why the privileging gap is consequential: when the surgeon cannot independently interpret slides, the benefits of integrated clinicopathologic correlation, rapid feedback, and end-to-end quality control are attenuated. One clinically important consequence is tissue conservation: because margin status is established microscopically rather than inferred from empiric margin width, tissue removal can remain tightly focused. In collaborative or fragmented models, greater interpretive uncertainty may promote wider re-excision—a concern especially relevant for tumors in functionally critical sites such as the nasal ala, eyelid margin, digit, or genitalia.

The unexpected value of complete examination

The complete-margin approach of MMS offers benefits beyond tumor clearance. Incidental findings identified during MMS span a broad spectrum, from benign adnexal proliferations to clinically significant malignancies. As noted above, Cooper *et al.*[12] reported that most incidental findings prompted additional intervention, and Cohen *et al.*[13] described recurrent ductal carcinoma

in situ detected during MMS for BCC of the nipple. These observations highlight that the histopathologic completeness of MMS creates a diagnostic window that standard sampled-margin techniques may not provide, and that this window is most likely to be appreciated when interpretation is integrated with direct clinical knowledge. Current consensus statements in Chinese dermatologic surgery acknowledge the importance of MMS[17] but do not yet fully address the credentialing implications of independent frozen-section interpretation—an omission that reflects the broader privileging challenge explored throughout this review.

Appropriate use criteria and patient selection

The Appropriate Use Criteria (AUC) framework: when MMS is definitively indicated

The 2012 Appropriate Use Criteria (AUC), developed jointly by the American Academy of Dermatology (AAD), ACMS, American Society for Dermatologic Surgery Association (ASDSA), and American Society for Mohs Surgery (ASMS), remain the foundational framework for determining when MMS is appropriate, uncertain, or rarely indicated[18]. For BCC and SCC, which together account for the majority of MMS cases, several high-risk features consistently support the use of MMS over standard excision (Table 1).

Current National Comprehensive Cancer Network (NCCN) guidance reinforces these criteria. For SCC, support for MMS continues to expand: Turner *et al.* reported a local recurrence rate of only 3.3% for SCC treated with formalin-fixed tissue micrographic surgery despite 67% of tumors having high-risk features[19], and Motley and Arron noted that recurrence rates of approximately 3% after MMS versus 8% after standard excision were consistent with prior systematic reviews[20]. Batra and Kelley[21] identified predictors of extensive subclinical spread (tumors ≥ 25 mm: odds ratio [*OR*] 6.2; morpheaform BCC of the nose: *OR* 6.9; recurrent BCC of the nose: *OR* 5.7; ear helix: *OR* 4.8), and Song *et al.*[22] demonstrated that immunosuppressed patients may harbor more aggressive and clinically inapparent extension (*OR* 2.74).

Importantly, the AUC were developed within healthcare systems in which the surgeon performing MMS typically has independent authority to interpret frozen sections. When that assumption does not hold, the biologic rationale remains valid but implementation becomes more complex—a distinction central to the institutional adaptation framework proposed later in this review. In China, many dermatologists possess the practical skills needed for Mohs-specific slide interpretation, yet in most institutions there is no unified national framework authorizing dermatologists to independently sign frozen-section reports[17]. The limitation is therefore not simply one of training, but of credentialing.

Table 1: High-risk features prompting consideration of Mohs micrographic surgery for basal cell carcinoma and squamous cell carcinoma.

Risk category	BCC indicators	SCC indicators
Anatomic site	H-zone of face (periorbital, nasal ala, lip, and ear), genitalia, hands, feet, and nail unit	Same high-risk zones; particularly lip and ear
Size	> 2 cm on trunk/extremities; > 1 cm on face	> 2 cm; > 1 cm on high-risk sites
Histology	Morpheaform, infiltrative, micronodular, mixed	Poorly differentiated; desmoplastic; perineural invasion
Clinical behavior	Recurrent tumor, ill-defined borders	Recurrent; rapidly growing; arising in scar/chronic ulcer
Patient factors	Immunosuppression (organ transplant, hematologic malignancy)	Immunosuppression; genetic syndromes (xeroderma pigmentosum)
Prior treatment	Positive margins after standard excision	Positive margins; prior radiation field

Adapted from Connolly *et al.*[18] and NCCN Guidelines (v1.2026).
Abbreviations: BCC, basal cell carcinoma; SCC, squamous cell carcinoma; NCCN, National Comprehensive Cancer Network.

Melanoma: a controversial but evolving indication

The use of MMS for melanoma remains one of the most debated applications of the technique. Unlike keratinocyte carcinomas, for which MMS is widely accepted in appropriate high-risk settings, melanoma has traditionally been managed with wide local excision using predetermined margins based on Breslow thickness[23].

This approach remains standard for most invasive melanomas.

Nevertheless, evidence supporting a selective role for MMS in melanoma continues to grow. In a landmark study, Zitelli and Brown[24] reported outcomes in 535 patients and found that margin-controlled excision with frozen-section analysis could achieve excellent local control while preserving tissue. In that series, 83% of melanomas were completely excised with a 6-mm margin, and the 5-year local recurrence rate was only 0.5%. More recently, Shah *et al.*[25] concluded in a 2024 clinical review that MMS appears effective for melanoma *in situ* and selected thin invasive melanomas, especially in anatomically sensitive sites where standard wide margins may produce substantial cosmetic or functional morbidity. Miller *et al.*[26], in an accompanying editorial, emphasized the need for standardized immunostaining protocols as the use of MMS for melanoma expands, particularly the optimized use of markers such as human melanoma black 45 (HMB-45) and melanoma antigen A (Melan-A) to improve diagnostic confidence on frozen sections. Supporting this trend, Freeman *et al.*[27] reported substantial inter-rater reliability ($\kappa = 0.68–0.75$) and almost perfect intra-rater reliability ($\kappa = 0.90$) among ACMS-certified Mohs surgeons assessing melanoma antigen recognized by T cells 1 (MART-1)-stained frozen sections for melanoma margins, providing evidence that melanoma margin interpretation during MMS can be reproducible in trained hands.

Even so, the controversy is understandable. For melanoma *in situ* involving the face, eyelid, or nasal ala, MMS offers the advantage of complete margin control while minimizing sacrifice of normal tissue. In these settings, standard margins may lead to substantial reconstructive morbidity. However, in thicker invasive melanoma, management often involves broader oncologic considerations, including sentinel lymph node biopsy, pathologic staging, and systemic treatment planning. In such cases, the staged and time-intensive nature of MMS may be less well aligned with the overall treatment pathway.

In our view, MMS for melanoma should remain selective—most appropriate for melanoma *in situ* and selected thin invasive melanomas in cosmetically or functionally critical locations, not a universal replacement for wide local excision in intermediate-thickness or thick invasive melanoma where standard oncologic staging and multidisciplinary management remain paramount.

Extended indications: beyond keratinocyte carcinoma

Although BCC and SCC remain the core indications for MMS, the technique also has important applications in selected non-keratinocyte malignancies for which complete margin assessment and tissue preservation are especially valuable.

Dermatofibrosarcoma protuberans (DFSP). Among the extended indications, DFSP is one of the most compelling. Because of its infiltrative growth pattern and tendency toward extensive subclinical spread, margin control is critical, and MMS has consistently demonstrated lower recurrence rates than wide local excision. This topic is discussed in greater detail in the outcomes section below.

Extramammary Paget disease (EMPD). EMPD is another important indication because of its multifocal and clinically inapparent peripheral extension. Evidence-based clinical practice guidelines by Kibbi *et al.*[28] recommend MMS as a first-line treatment option in appropriate cases. Classification-tree analysis of 150 EMPD cases treated with MMS has identified clinical and histopathologic predictors of margin width, thereby supporting more individualized preoperative planning[29]. Modified peripheral margin techniques, including the so-called spaghetti technique—a staged peripheral margin excision approach in which a narrow strip of tissue is removed circumferentially around the clinically apparent lesion and processed as permanent sections—may be particularly useful in EMPD because of its discontinuous growth pattern[30]. Chinese experience also supports feasibility in Asian populations. Wan *et al.*[31] reported 28 EMPD patients treated with peripheral-tissue MMS with a local recurrence rate of 10.7%, and Zhao *et al.*[32] described similar successful application in axillary EMPD.

Rare cutaneous malignancies. MMS has also been used successfully for a number of rare tumors characterized by irregular subclinical extension, including Merkel cell carcinoma, microcystic adnexal carcinoma, and eccrine porocarcinoma. Li and Yang[33] reported two cases of

Merkel cell carcinoma treated with modified MMS without recurrence at 13 and 15 months of follow-up. Zhang *et al.*[34] described five cases of adnexal malignancy treated with MMS, likewise without local recurrence over 1–5 years of follow-up. Although these reports are limited by small sample size, they support the biologic logic for margin-controlled surgery in tumors that are difficult to define clinically.

Functionally critical sites: nail unit and genitalia. Certain anatomic locations justify MMS not only because of recurrence risk, but also because the consequences of tissue loss are disproportionate. In the nail unit, both SCC and melanoma *in situ* may require digit-sacrificing procedures if treated with conventional wide excision. In this setting, MMS or slow Mohs approaches can permit margin control while preserving function[35–37]. Similarly, Greenzaid *et al.*[38] concluded in a systematic review that MMS is a viable treatment option for penile SCC, where tissue preservation has direct implications for urinary, sexual, and psychological outcomes. In such settings, the alternative to MMS may be not merely a wider scar, but loss of a critical anatomic structure.

Patient-reported outcomes

Because MMS is typically completed in a single coordinated treatment episode, it may reduce anxiety associated with delayed pathology results and positive-margin callbacks. For facial tumors, enhanced tissue preservation may simplify reconstruction and shorten recovery. Prospective research on patient-reported outcome measures (PROMs) remains limited but growing. Veldhuizen *et al.*[39] reported that quality of life and aesthetic satisfaction improve over the first postoperative year. Fagan *et al.*[40] further identified clinical and psychosocial factors associated with quality-of-life outcomes after MMS. Although this evidence base is still emerging, it indicates that patient experience should be considered alongside recurrence, tissue preservation, and cost when assessing the overall value of MMS.

Technical execution

Preoperative assessment: beyond the naked eye

The success of MMS begins before the first stage is excised. For tumors with infiltrative growth, recurrence, or discontinuous spread, the visible lesion may represent only a portion of the true tumor burden. High-frequency ultrasound (HFUS) has emerged as a useful adjunct: in DFSP, HFUS-assisted MMS can improve delineation of tumor depth and lateral extension[41,42]. Three-dimensional reconstruction techniques may extend this concept further[43]. For SCC, predictive modeling may assist case planning: Lin *et al.*[44] developed a nomogram for subclinical extension in a Chinese patient population, highlighting that patterns of spread may vary across populations. Fluorescence-guided approaches offer another strategy: Peng *et al.*[45] reported 5-aminolevulinic acid fluorescence-guided MMS in EMPD. Huang *et al.*[46] described a real-time augmented reality robotic system integrated with artificial intelligence (AI) for skin tumor surgery in 106 cases, including 16 MMS procedures, with submillimetric localization precision, although long-term outcome data remain limited. Other adjunctive techniques (dermoscopy, reflectance confocal microscopy, optical coherence tomography) remain supplementary and do not replace the histologic confirmation that defines MMS.

Intraoperative technique: mapping, margins, and innovation

Tissue removal and mapping: the foundation of precision

The technical sequence of MMS consists of three linked steps: excision of a thin tissue layer encompassing the clinically apparent tumor and a narrow peripheral margin, processing as a horizontal frozen section, and precise correlation of microscopic findings with the operative map. A beveled excision at approximately 45 degrees facilitates convergence of the peripheral and deep margins into a single horizontal plane. Initial margin width is generally narrow—1–2 mm for many BCCs, 2–3 mm for aggressive SCC—because the purpose is complete margin assessment followed by selective re-excision, not definitive blind clearance.

Mapping is central to this process. Traditional Mohs maps divide the specimen into anatomically corresponding sections with systematic color coding to preserve orientation, creating a reproducible visual language through which microscopic findings can be translated back

to the patient. Flattening of tissue before freezing is equally important: at curved anatomic sites, incomplete flattening may cause portions of the true margin to be underrepresented or distorted.

Frozen section processing: the technical core of MMS

The reliability of MMS depends on the quality of frozen-section preparation. Tissue is embedded in optimal cutting temperature compound, rapidly frozen, sectioned at 4–6 μm, and stained with hematoxylin and eosin. Rapid freezing minimizes ice crystal artifact; consistent staining is essential—excessive hematoxylin or eosin can obscure diagnostic detail, while understaining may make residual tumor difficult to distinguish from stroma. The technical quality of the section is inseparable from the diagnostic quality of interpretation. Sectioning strategy is guided by the goal of obtaining an interpretable representation of the true peripheral and deep margin while minimizing tissue loss and artifact.

Margin interpretation: the practical value of integrated clinicopathologic correlation

The advantages of integration described above take on practical significance during margin interpretation. In routine practice, the significance of a frozen-section finding often depends on contextual knowledge unavailable on the slide alone: ambiguous basaloid structures may represent residual BCC, adnexal epithelium, tangential sectioning, or compression artifact; subtle perineural invasion may be more readily appreciated when the interpreter is aware of the anatomic site and clinical extension pattern. The surgeon who created the defect knows where tissue was thin, where flattening was difficult, and where processing artifact is most likely to occur. When interpretation and surgical decision-making are integrated, the interval between finding and action is measured in minutes, reducing the risk that histologic ambiguity will translate into incorrect or unnecessarily extensive re-excision.

Collaborative diagnosis: workflow structure and institutional requirements

In Type II institutions, the classic excision-interpretation loop is shared between the dermatologic surgeon and a pathologist. This model can preserve the central technical goal of MMS—complete margin assessment through horizontal sectioning and mapped re-excision—while redistributing interpretive responsibilities within the institutional framework. Published Chinese case series suggest that favorable outcomes can be achieved in selected settings when the workflow is well organized[31–33].

At the same time, this collaborative structure introduces distinct workflow requirements. Surgical and histologic information must be integrated across two professionals instead of within a single operator. Quality assurance is shared, placing greater importance on specimen orientation, tissue handling, mapping accuracy, and standardized protocols. Intraoperative decision-making may proceed through a more sequential process. Type II institutions should not be viewed as failed approximations of the integrated model, but as context-responsive systems whose success depends on coordination, technical consistency, and shared interpretive discipline.

These workflow requirements have measurable consequences. Roy and Parwani documented communication errors in 2.7% of frozen-section cases—fortunately all of minor clinical impact—with predominant mechanisms being surgeons' misinterpretation of deferred diagnoses and pathologists' use of nonspecific terminology[47]. These mechanisms are structurally amplified in Type II Mohs workflows. Interpretive discordance is likewise inherent to diagnostic practice: in a second-opinion dermatopathology review of 358 malignant neoplasms, 10.3% of diagnoses were discordant and management changed in 8.9% of cases[48]. Notably, discordance was highest among dermatologists without dermatopathology fellowship training, underscoring that what controls interpretive error is subspecialty training and structured review—not professional identity *per se*. This is consistent with recurrence-audit studies identifying technical and interpretive error as the predominant—and modifiable—cause of local recurrence after MMS[14,15]. It must be acknowledged that no published study directly quantifies the proportion of additional surgical stages, unnecessary tissue removal, or incomplete excisions attributable to collaborative rather than integrated interpretation. The vulnerabilities described above are mechanistically plausible and consistent with available data, but their magnitude in Type II Mohs practice remains unknown—generating

such comparative data is a priority of the prospective multicenter registries proposed in the roadmap below.

The pathologist's perspective further illuminates the institutional constraints of Type II systems. China faces a well-documented shortage of pathologists, with the workforce concentrated in tertiary hospitals; the national guideline itself sets a staffing benchmark of one to two pathologists per 100 hospital beds, a standard many institutions struggle to meet[49]. Moreover, because rapid intraoperative diagnosis is restricted to pathologists holding intermediate-or-above titles with at least five years of experience, the frozen-section burden concentrates on a small senior workforce[49]. Three structural mismatches compound this constraint. First, interpreting pathologists often lack the dermatologic clinical context—lesion morphology, prior biopsy results, the surgeon's mapping intent—needed to contextualize borderline findings. Second, intraoperative frozen-section services compete across surgical departments, so Mohs procedures, which are iterative and unpredictable in timing, cannot always be prioritized. Third, standard pathology workflows are calibrated for general surgical specimens: routine cryostats may not reach the lower temperatures optimal for sectioning skin and adipose tissue, adipose-rich specimens fragment during cutting, and horizontal *en face* sectioning with Mohs mapping conventions differs fundamentally from routine vertical processing—together requiring equipment, technique, and training that general pathology services do not routinely provide.

In our own Type II practice, the section-quality dimension of this separation has been a recurring constraint. Because pathology technicians process specimens from multiple clinical departments concurrently, Mohs specimens cannot always be embedded with the case-by-case attention that complete *en face* embedding requires; in our experience, the proportion of Mohs sections lacking epidermis, dermis, or subcutaneous tissue is markedly increased, and genuinely serial sectioning—and with it, truly 100% margin evaluation—is difficult to achieve in routine practice. In addition, technicians sometimes trim tissue blocks for technical reasons, and trimming can detach the ink applied to mark orientation, so that tissue orientation and the location of residual tumor become difficult to determine under the microscope. Because technicians and Mohs surgeons work in physically separate locations, immediate communication and real-time feedback on section quality are not possible; the mutual-accommodation period between the surgical and laboratory teams is markedly prolonged, and section quality improves only slowly. We present these as single-center institutional observations, offered as hypothesis-generating; they define concrete, measurable endpoints—section completeness, orientation integrity, and feedback turnaround—for the prospective studies proposed in the roadmap below.

Why independent slide reading matters: evidence for the integrated model

The transition from collaborative diagnosis to independent slide interpretation should not be framed solely as a matter of professional autonomy. It also concerns diagnostic accuracy, workflow integrity, and quality assurance.

First, studies of diagnostic concordance support the interpretive competence of fellowship-trained Mohs surgeons. Herrera *et al.*, in a systematic review of nine studies comprising 11,190 Mohs frozen-section slides, found concordance rates ranging from 94.90% to 99.79%[50]. Mariwalla *et al*. reported 99.7% concordance for clinically significant decisions in 1,156 slides[51]. Chia *et al.* found 93.60% concordance for tumor status and 98.90% for tumor type, with no discordant case changing patient management[52]. These studies suggest that appropriately trained Mohs surgeons can interpret frozen sections with a high degree of reliability.

These concordance data, however, speak to individual capability, and individual capability alone cannot carry the argument from competence to institutional authorization. The decisive feature of the Type I model is not that fellowship-trained surgeons are individually skilled interpreters, but that the fellowship training system embeds quality assurance directly within the surgical encounter. Murphy *et al.* documented this process quantitatively over a one-year fellowship: with the attending Mohs surgeon prereading every slide and reviewing all sections jointly with the fellow at a dual-headed microscope, critical interpretation errors declined to fewer than one per 100 cases only after approximately six months

and 1,491 cases of mentored practice; notably, at the 500-case minimum required by accredited fellowship programs, the critical error rate was still approximately 7 per 100 cases[53]. Independent interpretive capability is therefore not an inherent attribute of the surgeon but a product of sustained, mentored case accumulation within a structured training environment—and the corrective mechanism that produces it, embedded in the surgical encounter itself, cannot be fully replicated across the Type II handoff, because the interpreter is structurally separated from the surgical context.

Second, quality audits indicate that technical and interpretive failures remain important causes of recurrence. Campbell *et al.*[14] found that residual tumor was visible at the margins of original slides in a subset of recurrent cases, and Van Lee *et al.*[16] identified acceptance of poor-quality slides as a modifiable contributor to incomplete excision. Although these studies do not directly compare integrated and collaborative models, they support the broader principle that MMS quality depends on close control of both specimen preparation and interpretation.

Third, outcome data indirectly support the value of integrated practice. Large cohort studies consistently show that MMS achieves lower recurrence rates than standard excision for selected tumors[1,54]. Because integrated interpretation strengthens clinicopathologic correlation and shortens the feedback loop, it is reasonable to infer that independent slide reading contributes to the fidelity of the classic MMS model. However, direct prospective comparisons between Type I and Type II systems remain unavailable, representing an important evidence gap.

For this reason, the argument for independent slide reading is best framed as a systems claim: the Type I training system can build and maintain the quality-assurance mechanisms that safe independent practice requires, and institutional authorization should follow from that demonstrated system capacity. Collaborative diagnosis remains a pragmatic adaptation where credentialing does not yet permit the integrated model; the field should define how transitions toward independent interpretation can be evaluated safely and prospectively.

Complex case management and adjunctive therapies

Although MMS is fundamentally a margin-controlled surgical technique, some tumors require multimodal management. Adjunctive therapies may be considered in selected cases, but their role should be defined by tumor biology rather than reflexive escalation.

In locally advanced BCC, the use of adjunctive photodynamic therapy (PDT) alongside MMS has generated interest, but the available data require cautious interpretation. Gahimbare *et al.*[55] reported a higher recurrence rate in patients treated with MMS plus PDT than in those treated with MMS alone; however, this difference was likely driven by selection bias, as the combination-therapy group contained a disproportionate number of aggressive tumors. The findings therefore do not demonstrate harm from PDT, but neither do they establish clear added benefit. Similarly, Yu *et al.*[56] found no statistically significant difference in recurrence between surgery plus PDT and MMS in difficult-to-treat BCC, although healing time was longer in the combined-treatment group and costs were lower. These findings suggest that combination approaches may have a role in selected resource-constrained settings, but they do not displace MMS as the reference standard.

For EMPD, adjunctive radiotherapy may offer benefit in selected high-risk cases. Zhang *et al.*[57] reported a 5-year local recurrence-free survival rate of 97% among 87 patients treated with MMS plus adjuvant radiotherapy. While encouraging, such findings should be interpreted in light of case selection and disease biology. More broadly, these studies underscore that MMS can function as part of a multidisciplinary treatment platform, but adjunctive therapies should be used on the basis of evidence and indication rather than as routine "insurance."

Safety profile: from single-center cohorts to nationwide validation

MMS has an excellent safety profile, even though it is often used for anatomically complex, recurrent, or high-risk tumors. Early prospective data from Cook and Perone[58] (1,343 cases) showed an overall complication rate of 1.64%, predominantly minor hemostatic issues. Merritt *et al.*[59] (13 centers, 1,550 patients) documented

no major complications and a 2.60% minor complication rate. Kimyai-Asadi *et al.*[60] (3,937 patients) confirmed that major complications were exceedingly rare in both office-based and hospital-based settings.

Large-scale registry data have confirmed these findings. Alam *et al.*[61] reported an adverse event rate of only 0.72% across 20,821 procedures at 23 centers, and Ruiz-Salas *et al.*[62] found similarly low rates in the Spanish Registry of Mohs Surgery (REGESMOHS) cohort. These data indicate that MMS should be regarded as a standard outpatient procedure within properly trained and quality-controlled environments. Standardized perioperative protocols can further reduce already low complication rates[63].

Outcomes and evidence

Basal cell carcinoma: the foundational evidence

The evidence base supporting MMS in BCC is anchored by two landmark randomized controlled trials. In a multicenter randomized trial, Smeets *et al.*[64] compared MMS with standard excision for facial BCC and, at 30 months, found no statistically significant difference for primary BCC (2% vs. 3%, $P = 0.724$) or recurrent BCC (3% vs. 0%, $P = 0.119$). The 5-year follow-up by Mosterd *et al.*[65] proved clinically decisive: recurrence remained similar for primary facial BCC (2.5% vs. 4.1%, $P = 0.397$), but for recurrent facial BCC, MMS achieved significantly lower recurrence (2.4% vs. 12.1%, $P = 0.015$; Cox hazard ratio [*HR*] 5.390). At 10 years, the cumulative recurrence probability for recurrent BCC was 3.9% for MMS versus 13.5% for surgical excision ($P = 0.025$).

Observational evidence has further reinforced the role of MMS in higher-risk BCC. Shi *et al.*[66] reported a disease-free survival rate of 98.9% among 476 high-risk BCCs (American Joint Committee on Cancer [AJCC] T2/T3) treated with MMS at a single center, with only five local recurrences and no metastatic events. Although observational studies cannot substitute for randomized data, such findings support the durability of disease control achieved with MMS in aggressive and anatomically complex tumors.

At the meta-analytic level, Fraga *et al.*[67] conducted a systematic review and meta-analysis of 28 studies comparing complete margin assessment (CMA) with sectional assessment (SA) in high-risk keratinocyte carcinomas. Pooled locoregional recurrence rates were significantly lower with CMA across all keratinocyte carcinomas (3.9% vs. 13.5%, $P = 0.001$), cutaneous SCC with perineural invasion (9.8% vs. 32.0%, $P < 0.001$), and recurrent BCC (4.4% vs. 11.9%, $P < 0.001$). This meta-analysis provides the highest-level synthesis supporting the value of complete margin assessment *per se*—the structural feature shared by both Type I and Type II—without distinguishing who performs the interpretation[67].

Taken together, the BCC literature supports a tiered conclusion: randomized evidence clearly favors MMS for recurrent facial BCC, while the indication for primary BCC rests on a combination of observational outcomes, biologic plausibility, and the known advantages of complete margin assessment in tumors at risk for subclinical extension.

Squamous cell carcinoma: strengthening evidence for high-risk disease

Compared with BCC, the evidence base for cutaneous SCC has historically been less mature, but this is changing rapidly. Recent multicenter data strongly support the use of MMS for high-risk SCC. In a 2025 multicenter validation study involving 12 centers and 938 Brigham and Women's Hospital (BWH) T2b/T3 SCCs, Wang *et al.*[68] directly compared MMS with wide local excision and found that MMS was associated with significantly lower local recurrence and disease-specific mortality using inverse probability of treatment weighting Fine-Gray models. Three-year local recurrence rates were 18.9%–20.0% for standard excision versus 8.2%–9.6% for MMS. This work validated an earlier single-center study by Wang *et al.*[69] which first identified a recurrence and survival advantage for MMS in high-stage SCC.

Location-specific data further support these findings. Veerabagu *et al.*[70] reported a local recurrence rate of only 1.7% among 117 nail-unit SCCs treated with MMS, markedly lower than the historical recurrence rates reported for conventional surgery in this anatomically and functionally critical site. Taken together, these studies

indicate that complete margin assessment is especially valuable in SCC with aggressive biology, high-stage features, or functionally sensitive location.

Immunosuppressed patients

Immunosuppressed patients represent a particularly important subgroup because SCC in this population often behaves more aggressively and carries greater risk of recurrence and metastasis. Xiong *et al.*[71] analyzed 366 primary BWH T2a SCCs, of which 32.5% occurred in immunosuppressed patients, and found that wide local excision was associated with nearly fivefold greater local recurrence risk compared with MMS (*OR* 4.8; 95% *CI* 1.1–21.6), while immunosuppression itself independently increased recurrence risk (*OR* 5.1; 95% *CI* 1.1–23.3). In a matched cohort of head and neck SCC, Li and Schmalbach[72] found that solid-organ transplant recipients treated with MMS did not experience worse disease-free or overall survival than immunocompetent controls, with only one local recurrence among 17 transplant recipients at a mean follow-up of 46 months.

These institutional findings are supported by prospective registry data. In the REGESMOHS cohort, which included 5,226 patients and 157 immunosuppressed individuals, immunosuppression was associated with an adjusted recurrence incidence rate ratio of 2.79[73]. Importantly, this finding does not suggest failure of MMS; rather, it underscores the elevated baseline risk of recurrence in this population and the need for treatment strategies that maximize margin control.

The consequences of recurrence in SCC can be severe. Sun *et al.*[74] reported that among patients with recurrent cutaneous SCC of the head and neck following surgery and postoperative radiotherapy, 1-year overall survival was only 43.2%, with a median survival of 8.4 months. Outcomes were substantially better only in patients eligible for salvage surgery. These data emphasize that recurrence is not a trivial event, and they reinforce the importance of optimal initial surgical management. In this context, MMS may be especially valuable for immunosuppressed and otherwise high-risk patients because it minimizes the likelihood of leaving residual disease at the primary operation.

Overall, the evidence supports a nuanced but increasingly firm conclusion: MMS provides important oncologic benefit in high-risk SCC, and that benefit may be particularly consequential in immunosuppressed patients and in tumors arising in anatomically complex sites.

Melanoma: evidence in evolution

The evidence for MMS in melanoma remains heterogeneous and highly dependent on disease stage and anatomic site. For melanoma *in situ* (MIS), the available data suggest that both MMS and conventional excision can provide excellent local control in appropriately selected cases. An Australian cohort study of 351 small MIS lesions at low-risk sites reported a recurrence rate of only 0.9% at a median follow-up of 7 years with a 5-mm clinical excision margin, a result comparable to the recurrence rates reported in prior MMS series[75]. In a comparative study of 662 MIS lesions, no statistically significant differences were found between MMS and wide local excision with respect to 10-year recurrence or melanoma-specific survival[76]. Although the 5-year recurrence rate numerically favored MMS (1.1% vs. 4.1%), this difference did not reach statistical significance, and propensity score adjustment further attenuated the association.

These findings suggest that for small MIS at low-risk sites, conventional excision with appropriate margins remains effective. The potential advantage of MMS becomes more relevant in lesions with greater likelihood of subclinical extension, especially those located in cosmetically or functionally sensitive areas.

For early invasive melanoma, the evidence appears to be anatomically stratified. In an analysis of 70,319 AJCC stage I melanomas from the National Cancer Database, MMS was associated with a modest overall survival advantage compared with wide margin excision after multivariable adjustment (*HR* 0.86; 95% *CI* 0.76–0.97), with the strongest signal observed in head and neck lesions[77]. By contrast, a separate large-scale study of 188,862 trunk and extremity melanomas found no significant difference in 5-year overall survival between MMS and wide local excision[78]. This pattern suggests that any advantage of MMS in melanoma is unlikely to be universal and may instead be concentrated in sites where

subclinical extension is common and tissue preservation has substantial reconstructive implications.

Acral and nail-unit melanomas provide particularly compelling examples of this site-specific logic. Retrospective data on hand and foot melanomas indicate that MMS reduced the rate of reconstruction performed in the setting of positive margins and shortened the interval to definitive reconstruction compared with conventional excision[79]. For nail apparatus melanoma *in situ*, Chinese experience offers important supporting data. A single-center study from Peking Union Medical College Hospital used slow MMS with formalin-fixed paraffin-embedded sections in 10 patients and reported no recurrences at a median follow-up of 46 months. The median excision margin was 8 mm, all patients underwent full-thickness skin graft reconstruction, and digital function was preserved[35]. Patients with Hutchinson sign required larger margins, highlighting the value of individualized planning even within this approach.

Overall, the available evidence supports a stage-site framework: wide local excision remains standard for most trunk and extremity melanomas, while MMS appears most useful for melanoma *in situ* and selected thin invasive melanomas in anatomically critical locations—head and neck, acral surfaces, and nail unit—where complete margin assessment may reduce repeat surgery and improve reconstructive planning.

Dermatofibrosarcoma protuberans: near-consensus

Clinical evidence and persistent challenges

DFSP is widely regarded as one of the strongest extended indications for MMS because of its infiltrative growth pattern and high propensity for subclinical extension. A systematic review and meta-analysis of 88 studies involving 4,324 patients or tumors found substantially lower pooled local recurrence rates after MMS than after wide local excision: 1.5% for MMS versus 9.4% for wide local excision in noncomparative studies[80]. Although the subset of 12 comparative studies did not show a statistically significant difference, the direction of effect consistently favored MMS.

The limitations of wide local excision in DFSP are also evident from margin-based analyses. A meta-analysis of 881 patients showed that wide local excision with margins of at least 3 cm was associated with significantly lower recurrence than excision with margins less than 3 cm (3.9% vs. 23.1%; relative risk 0.17; 95% *CI* 0.09–0.31)[81]. Positive-margin rates were likewise far lower with wider margins. These findings underscore the central challenge of DFSP surgery: when margin assessment depends on representative vertical sampling rather than exhaustive evaluation, even generous clinical margins may fail to capture occult extension. MMS addresses this problem through near-complete intraoperative margin assessment and has therefore achieved some of the most favorable recurrence outcomes reported for DFSP.

Long-term single-center studies support this conclusion. One cohort of 29 patients followed for a mean of 10.6 years reported no recurrences after MMS[82]. Similarly, a 10-year institutional review of 80 patients found no recurrences among MMS-treated patients, compared with a 20% recurrence rate after wide local excision with 1–3 cm margins[83].

Despite this apparent near-consensus, several limitations remain: the quality of evidence is low overall (no randomized trials, mostly retrospective), follow-up is often insufficient given DFSP's potential for late recurrence, fibrosarcomatous transformation is an important adverse prognostic factor[84], and the integration of neoadjuvant imatinib remains uncertain—one series found that imatinib reduced tumor volume but not final defect size and was associated with a 30% local recurrence rate, possibly because patchy regression complicated margin assessment[85]. DFSP can reasonably be regarded as a near-consensus indication for MMS, but one in which long-term surveillance and biologic risk stratification remain essential.

MMS for other cutaneous malignancies: sebaceous carcinoma and extramammary Paget disease (EMPD)

MMS also offers meaningful benefit in selected rare malignancies in which subclinical extension is common and tissue preservation is critical. Sebaceous carcinoma and EMPD are especially relevant in this regard.

For sebaceous carcinoma, Chinese investigators have contributed some of the largest comparative data currently available. In a multicenter cohort of 360 patients, MMS was associated with significantly lower local recurrence than wide local excision (15.7% vs. 39.6%; *HR* 0.42; 95% *CI* 0.24–0.73; $P = 0.002$), although rates of metastasis and tumor-related mortality did not differ significantly between groups[86]. Pagetoid intraepithelial neoplasia was not an independent predictor of local recurrence in that analysis, although the confidence interval was wide and does not exclude clinical relevance. Supporting these findings, an analysis of 1,265 patients from the National Cancer Database found a survival advantage for MMS and higher negative-margin rates compared with wide local excision[87].

For EMPD, a systematic review encompassing 23,493 patients across 483 studies found that MMS was associated with the lowest recurrence rate (11.2%), compared with 18.7% for margin-controlled surgery overall and 37.0% for wide local excision[28]. These findings are clinically important because EMPD often occurs in genital, perineal, or axillary sites where incomplete excision can carry substantial functional and reconstructive consequences.

Although the evidence supporting MMS in these tumors is increasingly persuasive, translation into practice depends on institutional capability. In particular, diseases such as EMPD illustrate how the benefits of complete margin control may be constrained not by technical impossibility, but by whether a health system permits efficient intraoperative interpretation and decision-making. This issue is taken up in greater detail later in this review.

Global implementation patterns

Type I: independent diagnosis

The United States most closely represents the Type I model of MMS implementation, in which the Mohs surgeon performs excision, directs or closely oversees tissue processing, and independently interprets the frozen sections within a single integrated workflow. Formal fellowship training remains the defining institutional feature of this model. In the United States, this has historically been structured through ACMS fellowships and, more recently, through Accreditation Council for Graduate Medical Education (ACGME)-accredited micrographic surgery and dermatologic oncology training pathways. This infrastructure produces surgeons trained in both cutaneous oncologic surgery and frozen-section interpretation.

The strength of the Type I model lies not only in technical integration, but also in the institutional ecosystem that supports it. Large prospective studies have shown that MMS performed by appropriately trained surgeons in office-based settings is associated with very low complication rates. Merritt *et al.*[59] documented low minor complication rates and no major complications in a multicenter prospective cohort, while Alam *et al.*[61] reported similarly low adverse event rates across 23 centers and 20,821 procedures. These data support the broader conclusion that MMS can be delivered safely and effectively as an outpatient procedure when the requisite training, technical standards, and workflow integration are in place.

A further component of the Type I system is specialized technical support. Histotechnicians working in Mohs settings require specific expertise in handling horizontally sectioned tissue, preserving specimen geometry, and producing sections that are diagnostically reliable for margin assessment. Mohs section technique differs fundamentally from routine pathology processing: the beveled excision must be flattened for *en face* embedding, and sectioning must achieve genuinely serial representation of the entire margin rather than representative sampling. In the U.S. Type I system, histotechnicians acquire these skills through on-the-job training within a dedicated Mohs setting, and the ACGME Program Requirements specify that accredited fellowships must include a laboratory component with defined quality standards[88]. In China's Type II system, by contrast, Mohs specimens are typically processed by pathology department technicians serving all surgical specialties simultaneously—Mohs cases cannot always be prioritized, standard cryostats may not be calibrated for skin and adipose tissue, and orientation markings may not be consistently preserved. As described above, these constraints have measurable consequences for section quality. Implementation frameworks that focus only

on surgeon training while overlooking technical infrastructure may underestimate the human capital required; dedicated Mohs histotechnician training should be recognized as a parallel priority, explicitly included within Phase 1 of the roadmap (described below).

From an implementation perspective, the Type I model depends on at least three prerequisites: standardized advanced training, institutional authority for independent intraoperative interpretation, and reimbursement structures capable of supporting the complete workflow. Its principal limitation is scalability. Even in the United States, training capacity remains finite, and the number of newly trained surgeons is insufficient to meet global need. Nevertheless, Type I remains the model most closely aligned with the original technical design of MMS.

Type II: collaborative diagnosis (modified MMS)

China represents the clearest example of the Type II model: the dermatologic surgeon performs excision and mapping, but slide interpretation occurs through collaboration with a pathologist. This model arises not primarily from lack of technical resources—major tertiary hospitals often possess frozen-section capability comparable to Western institutions—nor necessarily from individual technical capacity, as some dermatologists have substantial dermatopathology training. Rather, the limiting factor is institutional: current credentialing structures generally do not authorize dermatologists to independently issue frozen-section diagnoses. The Type II model is best understood as an adaptation to the privileging gap rather than to a purely technological deficit.

This adaptation should not be dismissed. Chinese clinicians have developed collaborative workflows that preserve complete margin assessment within existing institutional rules. Formalin-fixed tissue micrographic approaches provide one example: Turner *et al.*[19] showed that formalin-fixed techniques for SCC could achieve outcomes comparable to fresh-tissue micrographic surgery while using existing pathology infrastructure. At the same time, Type II systems introduce operational vulnerabilities: direct clinicopathologic correlation may be reduced, communication becomes more critical, and stage-to-stage decision-making may slow. These vulnerabilities, examined quantitatively earlier in this review, do not invalidate collaborative diagnosis but mean that its performance depends heavily on the maturity of the surgeon-pathologist relationship, technical support, and mapping protocol standardization. Published Chinese case series suggest that Type II collaborative MMS can achieve acceptable outcomes in selected tumor types[31,33,34], but these reports largely come from experienced centers and do not fully resolve the question of generalizability across institutions with varying support.

Type III: referral-based networks

The Type III model relies on referral rather than local execution of MMS. Community dermatologists or general surgeons identify high-risk lesions and refer patients to regional centers capable of providing Type I or Type II margin-controlled surgery. Complete margin assessment is achieved through system organization rather than on-site capability. The effectiveness of Type III systems depends on the quality of upstream triage: practical success requires that community clinicians can recognize high-risk tumor features. Predictive tools such as Lin *et al.* model for SCC subclinical extension[44] may help strengthen referral decisions. Type III should not be viewed as a low-resource fallback but as a functional specialization model that may serve as the first stage in broader system development, potentially supporting the emergence of regional Type II programs and eventually Type I centers.

From collaboration to independence: the institutional logic of transition

The preceding sections have argued that the defining advantages of classic MMS arise from the integrity of the excision-interpretation loop. If the technical design of MMS is optimized when excision and interpretation remain tightly linked, then Type II collaborative systems should be understood as pragmatic adaptations, but not necessarily as the final stage of institutional development where independent surgeon interpretation is feasible.

This argument should be made carefully. There are currently no prospective head-to-head studies directly comparing recurrence or quality outcomes between Type I

and Type II systems. The value of the technical core shared by both Types—complete margin assessment—is supported by randomized, multicenter, and meta-analytic evidence[65,67,68], but because margin completeness and interpreter identity vary together in those comparisons, they do not isolate the variable that distinguishes Type I from Type II. Accordingly, the claim made here is directional rather than comparative: the Type I arrangement is designed to eliminate the handoff risks inherent in Type II's separated workflow—while forgoing the external second review that separation provides; the net effect has not been measured, and the transition from Type II to Type I is therefore presented as a directional and phased hypothesis with a defined testing agenda (described in the roadmap below), not as an evidence-based conclusion. The transition should be understood not merely as a professional hypothesis, but as a quality-improvement pathway—one that builds on, rather than displaces, the collaborative foundations already established.

Historical precedent: the U.S. experience and implications for China

China's current institutional challenge is not historically unique. The United States itself underwent a prolonged period during which dermatologists performing Mohs surgery had to establish the legitimacy of independent frozen-section interpretation. Understanding this history is useful because it illustrates how privileging barriers may be reshaped through coordinated professional and institutional development.

The American experience unfolded over more than eight decades, and its defining feature was that the technique came first while standards and authorization followed. When Frederic Mohs first introduced chemosurgery in 1936, there was no training standard, no certification pathway, and no credentialing framework for the procedure; as early as 1953, Mohs himself had already experimented with fresh frozen tissue in place of zinc chloride fixation; this preliminary modification was later formalized by Tromovitch and Stegman in the 1970s, which made same-day margin-controlled surgery practical. Yet for decades the technique spread through individual mentorship rather than any formalized system. When Mohs founded the American College of Chemosurgery, later renamed the American College of Mohs Surgery, in 1967 as a professional home for the field, Mohs surgeons still did not enjoy automatic institutional acceptance as independent interpreters of surgical pathology. Early correspondence and historical commentary document skepticism from within medicine regarding whether surgeons without formal pathology-board certification should serve as final arbiters of margin status[89]. In that sense, the early American experience also reflected a gap between emerging technical practice and established credentialing structures.

The American response evolved through several converging strategies. First, standardized fellowship training: formal fellowship pathways were established in the 1970s–1980s, with the ACMS approving its first one-year programs in 1983. ACGME approved program requirements in 2003 and accredited the first five Procedural Dermatology fellowships in 2004—over documented opposition from plastic surgery, general surgery, and otolaryngology, with Nestler and Roenigk noting that "the most vocal opposition to accreditation came from those in the general surgery, plastic surgery, and otolaryngology specialties;"[90] the transition to ACGME accreditation was completed in 2014, when the fellowship was renamed Micrographic Surgery and Dermatologic Oncology. Current program requirements specify case volumes, interpretive competencies, and laboratory quality standards[88,90,91].

Second, formal certification: subspecialty certification was approved by the American Board of Medical Specialties in 2018—nearly three decades after an initial application had been denied in 1991[91]—and the first certifying examination was administered in October 2021, 85 years after the procedure was first performed. The initial denial is instructive: coming after two decades of practice and 37 College-approved fellowship programs, it demonstrates that certification was deliberately gated on the construction of an accredited training system rather than on demonstrated capability. The transitional attestation pathway acknowledged that experienced practitioners already existed before universal fellowship-based credentialing—a staged approach particularly relevant to countries seeking reform.

Third, evidence-based patient selection through appropriate use criteria; fourth, prospective safety and outcome

data from multicenter studies; and fifth, professional society advocacy. Together, these strategies helped translate technical practice into recognized institutional legitimacy.

The relevance of the U.S. experience does not lie in providing a model for direct replication, but in showing how privileging barriers may become more negotiable when training, certification, evidence generation, and professional advocacy develop in parallel. In the United States, practice preceded institutional safeguards in an environment without statutory restriction—no U.S. federal statute tied the authority to interpret one's own frozen sections to specialty identity, and interpretive legitimacy was constructed through training standards, laboratory regulation (including Clinical Laboratory Improvement Amendments [CLIA] 1988), professional privileging, and certification. The American experience was thus one of construction rather than statutory change: the gap was closed by building institutions, not by revising law. This observation is offered as evidence that safeguards can be constructed deliberately and timelines compressed, not as a recommendation that practice precede authorization where regulatory restrictions exist.

Toward Type I: a roadmap for China

If the American experience offers a historical precedent, it also suggests a practical logic for reform. Transition from Type II to Type I in China would likely require a staged process in which training standardization, evidence generation, certification, and quality assurance reinforce one another. This roadmap is offered not as a critique of current practice, but as a constructive framework for the next phase of institutional development—one that builds on the collaborative foundations already established by Chinese clinicians. Its purpose is specific and limited: to raise awareness of a genuine contradiction in the current Chinese system and to advocate reform of this arrangement. Under the national standardized residency training standards, dermatology residents complete a dedicated dermatopathology rotation, with specified slide-reading requirements that include common cutaneous tumors, and are examined on this training before completing residency[92]; upon entering practice, however, these physicians are not permitted to issue pathology diagnostic reports. Physicians are thus trained and examined in an interpretive competency that they are then not permitted to exercise in the surgical setting for which they were trained. The roadmap is intended to surface this tension and encourage dialogue about change—not to supply a finished legal blueprint for how that change should be enacted.

To understand why this tension persists, it is necessary to identify the specific regulatory provisions that produce it. The principal provisions governing this arrangement can be identified at the level of specific clauses. Article 14 of the Physicians Law of the People's Republic of China (effective March 1, 2022) requires physicians to practice within their registered practice scope, while also providing that a physician may add a practice scope after relevant training and successful assessment—subject to any qualification conditions prescribed by laws and administrative regulations for specific areas of practice. Article 24 prohibits physicians from issuing medical certification documents unrelated to their registered practice scope, and Article 57 attaches graduated penalties—fines, suspension of practice, and up to license revocation — to practicing beyond the registered scope[93]. Under the Interim Provisions on the Administration of Practice Scope in Physician Registration (2001), "Dermatology and Venereology" and "Medical Laboratory and Pathology" are listed as distinct registered practice scopes, and a change of scope requires approximately two years of systematic training at designated institutions followed by assessment[94]. Article 10 of the Guideline for the Construction and Management of Pathology Departments (Trial) (2009) further requires that physicians issuing pathology diagnostic reports hold clinical licensure plus a pathology professional-technical qualification, and that physicians performing rapid intraoperative diagnosis hold an intermediate-or-above pathology title with at least five years of slide-reading experience[49]. Read together, these provisions regulate the issuance of the pathology report of record; no principal provision identified here addresses intraoperative slide review undertaken by the operating surgeon to guide surgical decisions—an unaddressed space whose regulatory status would benefit from explicit clarification by regulatory authorities. Current laws and regulations do not explicitly grant surgeons independent authority to issue frozen-section

reports, nor do they categorically prohibit surgeons from participating in intraoperative pathologic assessment. In practice, surgeon review of intraoperative sections is a common component of the Mohs workflow in China; we describe this as the current regulatory landscape, not as a recommendation to practice ahead of explicit authorization, which nothing in this roadmap endorses. The pathology-specific qualification conditions that produce the privileging gap are set not by statute but by departmental normative documents; reform therefore may not require statutory amendment, and revision of, or interpretive guidance on, those documents by the National Health Commission may suffice—an action for which direct precedent exists, as the 2022 Measures for the Administration of Mutual Recognition of Medical Examination and Test Results created by departmental rule a new authorization channel for independent diagnostic reporting[95].

The American experience reviewed above provides context for this reform target, with an explicit boundary: the American gap was an absence of both credentialing standards and statutory restrictions on interpretive authority, which institution-building was able to supply; the Chinese gap combines restrictive normative documents with the absence of a credentialing framework, so the Chinese path requires institution-building plus normative revision or clarification. Neither path involves practicing ahead of authorization, and nothing in this roadmap should be read as recommending it. Later adopters also need not repeat the pioneer's timeline, because the standards, curricula, and quality metrics developed over those decades already exist as templates that can be adapted to local conditions[90,91].

Phase 1: training standardization

The most immediate need is the development of formalized Mohs training pathways. These should include supervised case requirements, structured competency assessment in both surgery and frozen-section interpretation, and a nationally coherent curriculum covering tumor biology, surgical technique, histopathology, reconstruction, and quality control. Existing tertiary centers with mature Type II practice are the most realistic candidates to serve as early training hubs, precisely because they have already accumulated the clinical experience and collaborative infrastructure on which formalized training can build. Training standardization should encompass not only surgeons but also histotechnicians: dedicated Mohs histotechnician training—covering *en face* embedding, serial sectioning of complete margins, and preservation of orientation markings—should be developed in parallel, as the technical quality of Mohs sections depends on a workforce whose expertise is specific to the Mohs workflow. Community dermatologists should simultaneously be integrated into structured referral systems (described earlier in this review) so that system development occurs at multiple levels.

Phase 2: evidence generation

Chinese centers are well positioned to generate the comparative data the international field currently lacks. Prospective multicenter registries could document recurrence, complications, patient-reported outcomes, and stage efficiency across both collaborative and independent practice models. Diagnostic concordance studies comparing surgeon and pathologist interpretation would also be valuable. Evidence generation should extend beyond recurrence to examine specimen quality, mapping errors, stage delays, communication failures, and re-excision patterns—quantifying the operational consequences of breaking the excision-interpretation loop. This validation agenda is, in a strict sense, one that only Chinese investigators can pursue: mature collaborative Type II systems exist at scale almost exclusively in China, and the prospective comparison required to test the transition hypothesis has never been performed.

Phase 3: certification and credentialing reform

Once standardized training and performance data are established, a board-style certification process could provide an objective signal of competence. Professional societies would need to engage hospital credentialing bodies and pathology governance structures to define circumstances under which certified Mohs surgeons could be granted independent frozen-section interpretation privileges. Certification is necessary but not sufficient: without revision or clarification of the normative documents identified above, a credential alone cannot confer report-issuing authority. Guidelines adapted to the Chinese healthcare context would also

be needed, including patient selection criteria, technical standards, documentation requirements, quality metrics, and peer review mechanisms.

Phase 4: implementation and quality assurance

In the longer term, mature Type II centers could begin carefully structured transition toward Type I practice, initially through highly trained and formally credentialed surgeons. This transition should be accompanied by robust quality assurance systems, including registries, complication reporting, peer review, continuing education, and periodic reassessment of interpretive performance. The goal is not to abandon collaborative models abruptly, but to complement them with independent capability where evidence and training support it.

The point of this roadmap is to preserve the quality advantages that define MMS while building an implementation model suited to China's institutional reality. The privileging gap should be viewed not as a permanent barrier, but as a transitional stage in the development of a more fully integrated system. The authors are practicing dermatologists and Mohs surgeons, not legal scholars; the clause-level description above is offered by clinicians who work within this regulatory environment, and a comprehensive legal and regulatory analysis is beyond the scope and expertise of the present work. Such analysis, conducted in collaboration with experts in medical law and health regulation, is identified as a priority for future interdisciplinary study.

Innovations and future directions

AI and the privileging gap: bridge, bypass, or both?

The privileging gap described earlier in this review refers to a mismatch between technical capability and institutional authority: clinicians may possess the skills needed for frozen-section interpretation, yet lack authorization to independently render intraoperative diagnoses. AI may help narrow this gap, but only if it is deployed as a tool for augmentation, validation, and training, not as a substitute for competence.

One potential role for AI is in generating more objective evidence for credentialing reform. Deep learning systems have demonstrated promising performance in detecting BCC on frozen sections, with reported slide-level area under the curve values approaching 0.90[96], and AI-assisted margin assessment platforms are moving closer to real-time intraoperative use[97]. Particularly relevant is the Generation, Assessment, Support (GAS) platform, a Chinese multicenter prospective study using more than 6,700 whole-slide images across eight centers, which found that AI improved pathologists' diagnostic confidence without replacing human judgment[98]. In this context, AI could function as a structured comparator or support system in studies of surgeon interpretive performance. If surgeons trained in Mohs surgery consistently demonstrate agreement with expert or AI-assisted consensus standards, such data could strengthen the evidence base for credentialing decisions.

AI may also have an important role in training. Digital case libraries, simulated frozen-section exercises, and AI-assisted feedback systems could help expand access to Mohs-related interpretive training without depending exclusively on live clinical volume. This may be especially valuable in countries seeking to expand fellowship-like training capacity more rapidly than current workforce pipelines allow. Competency-based assessment frameworks could eventually incorporate AI-assisted evaluation, although these applications remain early and should complement, not replace, expert supervision and real clinical experience.

At the same time, there is a substantial risk that AI could be misused as a bypass rather than a bridge. Large language models evaluated on Mohs surgery preoperative questions have shown only modest performance (59% accuracy)[99]. Any system that encourages clinicians to defer to algorithmic output without possessing the underlying interpretive skill would weaken patient care. AI should help accelerate progression from collaborative to independent models only when embedded within a framework of formal training, evaluation, and accountability.

Positioned within this review's framework, AI-assisted interpretation is best understood as "Type I with a technological adjunct" rather than a distinct delivery model: the surgeon retains interpretive responsibility,

with AI serving as a structured comparator, training tool, or quality-assurance layer. AI does not dissolve the privileging gap—the question of who is authorized to sign the intraoperative interpretation is unchanged—and AI does not make Type II structurally equivalent to Type I, because the handoff risks described earlier in this review arise from the physical and operational separation of excision and interpretation, which AI does not close.

Current state and implementation barriers

Despite rapid technical progress, most AI applications in Mohs surgery remain at an early stage. AI systems can assist with routine communication tasks but struggle with nuanced clinical decision-making[100]. Machine learning-based radiomic models have shown promise in predicting DFSP recurrence[101]. *Ex vivo* fluorescence confocal microscopy (FCM) represents another intermediate development: Longo *et al.*[102] reported 95.3% agreement between FCM and conventional frozen-section histopathology for SCC margin assessment. These technologies do not eliminate the need for the surgeon but may gradually reduce dependence on conventional processing steps.

Implementation remains the major challenge. Herrick *et al.*[103] identified three prerequisites for successful AI integration: standardized digital pathology infrastructure, personnel trained to interpret AI output critically, and workflow design that incorporates AI without disrupting operative efficiency. An algorithm cannot compensate for poor-quality tissue preparation, and medicolegal questions—particularly around responsibility when AI and surgeon disagree—remain human and institutional issues. Current innovations should therefore be interpreted as enabling technologies rather than replacements for the trained Mohs surgeon, aligning with the broader history of MMS itself: AI does not change the central goal of complete margin assessment but may provide new tools for achieving it more efficiently and reproducibly.

Conclusion

MMS has evolved into the reference standard for many high-risk cutaneous malignancies requiring precise margin control and maximal tissue preservation. The central advantage remains consistent: complete margin assessment integrated with immediate surgical decision-making.

This review argues that the global challenge facing MMS is no longer primarily one of proof of concept. The principal barrier to broader implementation is institutional—the privileging gap between clinical competence and institutional authorization to independently interpret intraoperative frozen sections. This distinction reframes the problem from resource scarcity to credentialing architecture, identifying a barrier amenable to institutional evolution, not fundamental resource reallocation.

China illustrates this challenge: many tertiary centers possess the technical elements for sophisticated margin-controlled surgery, and Chinese clinicians have developed collaborative workflows that deliver margin-controlled surgery within existing credentialing constraints. National guidance has increasingly recognized the value of Mohs surgery and staged permanent-section alternatives[104]. What remains is expanding the authorization framework so that qualified dermatologic surgeons can independently sign frozen-section reports where training and evidence support it.

The future of global MMS implementation is likely to be tiered: tertiary centers providing full MMS capability, regional hospitals adopting staged excision approaches, and community-based clinicians contributing through earlier recognition and referral. Emerging technologies, including AI, may facilitate this transition by strengthening training and diagnostic support, but should be understood as adjuncts rather than substitutes. The long-term goal remains unchanged: to ensure that clinicians performing margin-controlled surgery are trained, evaluated, and appropriately authorized to verify margin status with confidence and accountability.

MMS demonstrates that oncologic control and tissue preservation need not be traded against each other. Extending its availability will depend as much on institutional arrangements as on technical advance.

Author contributions

Qi Jue and John Z.S. Chen contributed equally to this article. Qi Jue drafted the manuscript and was

responsible for data curation and investigation, and John Z.S. Chen contributed to conceptualization and methodology, supervised and administered the project, and critically reviewed and edited the manuscript. Both authors reviewed and approved the final version of the manuscript and agreed to its publication.

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Ethics statement

Not applicable.

Data Availability Statement

No datasets were generated or analyzed for this work.

AI statement

During the preparation of this work the authors used an AI language model for assistance with language editing. The AI tool was not used for data analysis, data generation, image processing, or scientific content creation. All outputs were carefully reviewed and verified by the authors, who take full responsibility for the final content.

Conflicts of interest

The authors declare no conflicts of interest.

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