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REVIEW

Challenges in the Diagnosis and Management of Nail Melanocytic Disorders

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Abstract: Melanonychia significantly affects aesthetics and patient well-being, particularly when it advances to subungual melanoma. The causes of melanonychia are multifactorial, encompassing nail matrix melanocyte activation, benign melanocytic proliferation, subungual melanoma, as well as inflammatory, infectious, traumatic, and drug-induced conditions. Among these, subungual melanoma poses a diagnostic challenge due to its nonspecific clinical presentation, leading to delayed or missed diagnoses that adversely affect prognosis. Accurate differentiation between malignant melanonychia and more common benign etiologies—such as onychomycosis, trauma-related pigmentation, drug-induced pigmentation, and subungual warts—is essential to avoid both misdiagnosis and overtreatment. This review summarizes the clinical, dermoscopic, and histopathological characteristics of melanonychia of various origins; highlights key dermoscopic features for distinguishing subungual melanoma from non-melanocytic pigmentation; and outlines diagnostic and therapeutic strategies tailored to both adults and children. Clarifying these distinctions is critical for facilitating earlier recognition of nail melanoma while minimizing unnecessary interventions for benign conditions.

Keywords: melanonychia, nail malignant melanoma, diagnosis and treatment, dermoscope

Introduction

Melanonychia arises from a wide range of etiologies, including melanocytic activation, benign and malignant melanocytic proliferation, and inflammatory, infectious, traumatic, and drug-induced conditions. Among them, subungual melanoma is particularly challenging to diagnose due to its nonspecific clinical presentation, often resulting in delayed or missed diagnoses that adversely affect prognosis. Accurate differentiation between malignant melanonychia and more common benign etiologies (such as onychomycosis, trauma-related pigmentation, drug-induced pigmentation, and subungual warts) is essential to avoid both misdiagnosis and overtreatment. This review summarizes the clinical, dermoscopic, and histopathological characteristics of melanonychia of various origins; highlights key dermoscopic features for distinguishing subungual melanoma from non-melanocytic pigmentation; and outlines diagnostic and therapeutic strategies tailored to both adults and children. Clarifying these distinctions is critical for facilitating earlier recognition of nail melanoma while minimizing unnecessary interventions for benign conditions.

Nail and Melanocytes

The nail comprises two parts: the nail plate and the nail unit. The nail unit consists of several components, including the proximal nail fold, nail bed, nail matrix, and hyponychium, all supporting the nail plate. The nail plate is formed from the nail matrix, with the upper one-third derived from the proximal part of the parent material and the lower two-thirds from the distal part. Melanocytes, responsible for producing pigment and giving color to the nails, are present in the nail unit, particularly in the nail matrix and nail bed. The nail-fold skin contains melanocytes similar to those in typical epidermis.[1] The nail bed and nail matrix have significantly fewer melanocytes than normal skin, most located in the proximal nail matrix epithelium. Melanocytes within the proximal nail matrix remain quiescent and normally do not synthesize melanin. When this region is affected by disease or injury, the resulting alterations can manifest as various forms of nail plate dystrophy. These may include longitudinal or transverse ridges, surface irregularities, pitting, or increased

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fragility, depending on the specific nature of the underlying lesion.[2] Damage to the nail often originates from the distal nail matrix, which contains half of the active and half of the inactive melanocytes. Various physiological and pathological conditions can cause increased activity or proliferation of melanocytes, leading to increased pigment production in the nail matrix and extending to the distal tip of the finger/toe.

The distribution and characteristics of melanocytes in the nail matrix and bed are essential for early detection of subungual melanoma. Melanocytes are generally scattered irregularly in the basal and upper layers of the nail matrix epithelium and have abundant and uneven dendritic cytoplasm.[2] In contrast, the nail bed contains very few melanocytes, mainly in the basal layer, with small, inconspicuous dendritic structures. Traditional staining methods may not reveal these melanocytes, making it crucial to use specialized immunostaining techniques such as MITF, SOX10, HMB45 and MelanA to accurately visualize the thin, elongated nuclei of melanocytes and their clear cytoplasm.[3,4] However, there is also a risk of false negatives with these methods, emphasizing the need for multiple simultaneous immunostainings to avoid missing potential subungual melanoma cases. Therefore, clinicians can analyze the pigment position of the nail using melanin staining techniques, such as Fontana-Masson Staining or DOPA Staining, to preliminarily determine the source of melanin in the nail matrix, thereby guiding appropriate clinical biopsy and sampling.

Classification of Melanocytic Diseases

The causes of melanonychia are diverse and related to trauma, drugs, infections, and systemic diseases, and the incidence increases with age.[5–7] Melanocytic diseases are among the most common causes of melanonychia, including benign melanocytic hyperplasia and malignant melanoma of the nail, as well as conditions associated with increased melanocytic activity in the nail matrix.[8] The typical presentation of melanocytic disease is increased melanocyte count, leading to more melanin synthesis and formation of a pigmented nail band (longitudinal melanonychia). Melanonychia is defined clinically as partial or complete black/brown discoloration of the nail plate, extending from matrix to free edge. The causes of melanonychia primarily stem from two mechanisms: melanocytic activation and melanocytic hyperplasia. In adults, 70% of longitudinal melanonychia is caused by melanocytic activation, commonly seen in benign melanocytic diseases, referring to the active function of melanocytes under various factors without an increase in the number of melanocytes.[9] Histopathological examination shows melanocytes in or on the basal layer, with evident dendritic processes reaching the stratum spinosum.[10] Clinically, melanonychia can involve one or several nails with bands usually 2–4 mm wide (edges may be sharp or blurred). It often resolves when the cause is removed, but solitary lesions should be distinguished from primary melanoma.

Melanocytosis is a condition with an increased number of melanocytes in the nail matrix and is categorized as two types: benign and malignant proliferation. Benign melanocytic hyperplasia includes freckle-like nevi and nail nevi. Freckle-like nevi, more common in adults, show scattered melanocytes without nevus cell nests in tissue pathology. Nail nevi are more common in children and are characterized by at least one nest of pigment cells observed pathologically, usually at the epidermis junction. Statistics show 83.3% of children with longitudinal melanonychia have benign melanocytic proliferative lesions, with freckle-like nevi accounting for 66% and nail nevi accounting for 16.6%.[11] Some scholars argue that melanocyte proliferation poses a potential risk of malignancy. Subungual melanoma, a rare subtype of skin melanoma, is the malignant proliferation of melanocytes.[12] It includes in situ and invasive forms, has a high degree of malignancy, and carries a poor prognosis. Histologically, melanoma shows atypical melanocytes throughout the tissue layers; the nuclei are large, irregular, deeply stained, and often exhibit frequent mitoses.[13] Clinically, subungual melanoma may initially present solely as a dark longitudinal band. Distinguishing early melanoma from benign nevi (nail or freckle-like nevi) remains challenging.

Longitudinal melanonychia can be the initial indication of subungual melanoma in adults, significantly when a single plate is affected, histopathologically presenting as early atypical proliferation of nail melanocytes or typical subungual melanoma.[14] Studies show that in the United States, Caucasians have a much higher incidence of skin melanoma overall. Moreover, in darker-skinned populations, including non-Hispanic Black Americans and many Asian populations, acral lentiginous melanoma (including subungual melanoma) constitutes a disproportionately greater fraction of melanoma cases. In China, subungual melanoma accounts for approximately 17–19% of cutaneous melanoma cases among Chinese and Japanese patients.[15] Acral lentiginous melanoma exhibits a high degree of malignancy, is prone to metastasis, and

carries a poor prognosis, thereby necessitating heightened attention as a form of nail melanocyte disease. Owing to frequent misdiagnosis, the 5-year and 10-year survival rates for this disease stand at 30% and 13%, respectively.[2] Studies show that the diagnosis of subungual melanoma is often delayed, primarily due to the early clinical non-specific nature of the condition and the anatomical characteristics of the nail.[16,17]

Inflammatory and non-melanocytic conditions are among the most frequent causes of melanonychia, yet they are often mistaken for early subungual melanoma in clinical practice. Onychomycosis may lead to yellow-brown to black discoloration and typically shows the characteristic "ruin-like" pattern on dermoscopy. Melanonychia resulting from trauma tends to display uniform pigmentation with distal fading and usually lacks periungual extension. Drug-induced melanonychia—seen with agents such as chemotherapeutics, antiretrovirals (including azidothymidine), and minocycline—commonly involves several nails in a symmetric pattern and produces regular, parallel pigmented streaks. Subungual warts can appear as scattered brown-black dots, reflecting underlying hemorrhage. Onychocytic matricoma, although rare, is characterized by a sharply delineated pigmented band accompanied by thickening of the nail plate. Recognizing these diverse nail disorders and distinguishing them from melanoma remains essential, as timely diagnosis and intervention are critical for improving outcomes in subungual melanom.

Clinical Manifestations of Nail Melanocytic Diseases

Melanocyte activation is a reactive phenomenon triggered by factors such as trauma, pigmented onychopapilloma, medications, or infection.[18] Histologically, melanocyte density remains normal; only dendritic processes increase and pigment-bearing keratinocytes are seen. These melanocytes remain in the basal layer, with normal morphology (similar size to keratinocytes) and produce fine melanin granules.[19] A few melanocytes and melanin can also be seen in the dermis. When this condition manifests as lesions involving multiple nails, distinguishing it from subungual melanoma or actively treating it is often unnecessary. Some patients can naturally alleviate it after removing the triggers such as drugs, infection, and trauma.

The histological appearance of freckle-like nevi reveals a mild to moderate increase in melanocytes without nesting. A mild irregularity of cells, mainly in the basal layer, presents as a focal Paget-like distribution. Pigments in the epidermis are primarily distributed in the lower one-third, with a few pigments and phagocytic pigment cells visible in the dermis.[19–21] Nail nevi mainly exhibit the nesting distribution of melanocytes in the nail matrix, proximal nail folds, and subcutaneous area. Most lesions are junctional nevi or composite nevi, without abnormalities in melanocytes.

Subungual melanoma commonly affects the thumbs and first toenails of adults. Early subungual melanoma typically manifests as a solitary lesion. The color is frequently uneven, alternating dark and light pigmentation bands and unclear edges. Some pigment bands are wedge-shaped, displaying varying widths and thinness at the proximal and distal ends; notably, some are narrower distally which is a sign of growth. The lesions affect the surrounding skin, especially the proximal nail folds and distal hyponychium, and may be accompanied by plate damage, forming erosion and ulcers.[4] The histological manifestation is the proliferation of melanocytes in the nail matrix, which extends to the proximal nail folds and nail bed. It is characterized by an increase in the number and uneven distribution of melanocytes in the basal layer, with scattered melanocytes and occasional nesting. Melanocytes are seen in multiple foci and distributed in the epithelium in a Paget-like manner. The nuclei of tumor cells are large and deeply stained, with a large proportion of nuclear plasma and deep chromatin. They have thick melanin particles and long and prominent dendrites. Significant inflammatory infiltration can also be seen within the dermis.[16] Fully developed subungual melanoma exhibits the characteristics of lentiginous melanoma, with advanced tumor cells infiltrating into the dermis and forming invasive melanoma.

There are notable differences in the epidemiology and management of melanonychia between children and adults. In pediatric patients, longitudinal melanonychia is rare and usually represents benign nevi rather than melanoma. Nail matrix melanocytic nevi are the single most frequent cause of pigmented bands in childhood—studies estimate roughly 50% of pediatric melanonychia cases are nail nevi, and an additional ~30% are lentigines. Conversely, in adults melanonychia more often reflects benign melanocytic activation (eg, from racial pigmentation, trauma, or medications) than melanoma.[16] True subungual melanoma is exceedingly rare in children but becomes more likely in older adults.

Therefore, a new pigmented nail band in an adult warrants a higher suspicion of melanoma than the same finding in a child.

From a clinical perspective, pediatric melanonychia often displays features that would be alarming in adults, yet still be benign. Pediatric nail matrix nevi can present with dark brown-black bands, band widths >3 mm, involvement of the entire nail, and even pigment extending onto the proximal nail fold. One study of 28 biopsy-proven nail nevi found the average width of the pigmented band was significantly greater in children than in adults (covering ~47% of the nail in children vs 14% in adults) and 35% of pediatric cases had Hutchinson's sign, whereas none of the adult cases did.[22] Despite these concerning clinical findings, all of those pediatric cases were histologically benign. Adults, on the other hand, rarely have benign lesions that present with such dramatic features; a wide, irregular, multi-colored streak with periungual extension in an adult is far more likely to be melanoma and warrants urgent evaluation.

Diagnosis of Nail Melanocytic Diseases

In clinical practice, the widely adopted method for assessing the severity of nail melanocytic diseases is the "ABCDEF" standard.[23] The standard includes the following criteria: A for age, B for brown/black coloration, breadth, and border, C for change, D for distal involvement, E for tumor extension, and F for family history (Table 1). Recognizing the early signs of subungual melanoma, monitoring changes in skin lesions, and considering family history are crucial. Dermoscopy can aid in examining suspicious lesions, while histopathological biopsy may be required for a more precise diagnosis.

Histopathological Examination

Diagnosing subungual melanoma is particularly challenging, especially in children, where the role of biopsy remains debated. Some experts advocate early biopsy to avoid missed diagnoses; however, initial histopathological findings may suggest a benign condition, with malignancy only confirmed upon repeat examination. Moreover, childhood nail pathology (junctional nests, lentiginous proliferation, cytologic atypia) can mimic melanoma, creating diagnostic uncertainty. Thus, biopsy in children is generally reserved for true "red-flag" cases (rapid change, periungual extension, ulceration, bleeding). Although histopathological diagnosis is the gold standard, the unique anatomy of the nail poses challenges for obtaining pathological samples. Various biopsy techniques, such as punch biopsy, complete layer resection biopsy, etc., are available, depending on several factors, including position, width, depth, pigment origin, Hutchinson's sign, and the degree of malignancy of the bands[24–27] (Table 2).

Given that the proximal nail matrix produces ~81% of the nail plate, biopsy-related injury in this area carries the greatest risk of postoperative nail dystrophy.[28] This concern is particularly relevant in pediatric patients, where permanent deformity of the growing nail unit can occur. Therefore, many experts recommend a conservative "watch-and-wait" approach in children when lesions lack overtly malignant features. Notably, although some warn that observation risks missing early melanoma, pediatric series have so far reported no confirmed melanoma among many biopsied benign

Table 1 The ABCDEF Principles for Subungual Melanoma

Principle	Manifestations
A: Age	The age of onset ranges from 20 to 90, and peaked at 50~70. More prevalent in African American, Native American, and Asian individuals.
B: Band	The pigment band ranges from brown to black; Breadth ≥ 3 mm; Border: Irregular or blurry.
C: Change	Significant changes in nail pigment and rapid growth; Conventional treatment methods are ineffective.
D: Digit	The affected areas are the thumb > big toe > index finger. A single nail unit is more affected than multiple nail units, mainly impacting the fingernails.
E: Extension	Nail pigment affects the surrounding skin, the nail folds, or the free edge of the nail.
F: Family	Family history of melanoma and previous personal history of melanoma or dysplastic nevus syndrome.

Table 2 Indications and Characteristics of Biopsy Techniques for Nail Matrix

Biopsy Techniques	Best Indication	Characteristic
Punch biopsy	Pigment originates from the distal nail matrix, with a width of ≤ 3 mm	The resection range may be limited, potentially leaving malignant cells at the edge, while drilling multiple holes may increase the risk of permanent nail scarring.
Lateral resection biopsy	Pigment originates from the distal nail matrix, with a width>3mm	It only thins the plate; no permanent nail cracks are formed.
Longitudinal full layer resection biopsy	The pigment originates from the proximal nail matrix, with a width of 3–6mm	Full-layer nail specimens, including the subcutaneous layer, plate, nail bed, nail matrix, and nail folds, can be obtained, and the pathological results are reliable: Severe trauma and high risk of postoperative nail deformities.
Thin layer cutting biopsy	The risk of melanonychia malignancy is extremely low.	The nail matrix sample is only 0.5mm thick, with a low risk of postoperative nail dystrophy and partial recurrence of Melanonychia.

lesions. This supports careful surveillance rather than immediate biopsy. Parents should be involved in monitoring their child's nails and educated about red-flag changes.

In adults, diagnostic strategy differs significantly due to a higher baseline risk of malignancy. Longitudinal melanonychia exhibiting "ABCD" warning signs (Asymmetry, Border irregularity, Color variation, and Diameter >3 mm), Hutchinson's sign, or nail plate dystrophy typically warrants prompt biopsy of the nail matrix. Early intervention is critical because delayed diagnosis is strongly associated with worse prognosis. While current evidence does not indicate that biopsy accelerates melanoma spread, complete removal of the matrix lesion during biopsy is advised to reduce both the risk of recurrence and post-biopsy nail dystrophy. Scattered atypical melanocytes with deep nuclear staining and positive immunohistochemical staining of MelanA in the nail matrix sample can support the diagnosis of subungual melanoma.[10] However, the specific trauma, pain, and limitations associated with nail biopsies raise concerns among patients, potentially delaying the diagnosis and treatment of their condition. Clinicians must therefore balance procedural risks with diagnostic urgency and engage patients in shared decision-making.

Dermoscopy Evaluation

Early subungual melanoma often lacks typical clinical signs, making simple observation insufficient for accurate diagnosis. Dermoscopy offers a non-invasive tool to evaluate melanonychia and can help distinguish between melanocytic and non-melanocytic causes. Non-melanin–based pigmentation should be clearly differentiated, most commonly subungual hematoma, which typically appears as purple-red to brownish-black globules with filamentous ends and peripheral fading. Other important differentials include exogenous pigmentation (such as dyes, nicotine, or silver deposits) and infectious causes (eg, Pseudomonas or fungi). In contrast, melanocytic melanonychia usually presents as longitudinal pigmented bands with serrated proximal edges and variable coloration across the nail plate.[29] Recognizing these distinct dermoscopic patterns not only facilitates early detection of subungual melanoma but also helps to avoid unnecessary biopsies in benign conditions.

Dermoscopy often provides valuable clues when assessing melanonychia, as several non-melanocytic conditions display patterns that can easily be mistaken for subungual melanoma on clinical inspection alone. Becoming familiar with these benign dermoscopic features is crucial, as it helps clinicians avoid unwarranted biopsy procedures and prevents unnecessary interventions.

- Fungal melanonychia can present with a somewhat uneven yellow-brown hue, and in many cases the pigmentation broadens toward the distal edge of the nail, producing what is described as a reverse triangular pattern because the discoloration is wider distally than proximally. Dermoscopy may also reveal scattered longitudinal spikes, white longitudinal streaks, or irregular jagged borders near the proximal nail fold.[30] When these findings occur together, often accompanied by nail thickening and subungual debris, they more strongly support a diagnosis of onychomycosis rather than a melanocytic process.

- Drug-induced melanonychia often appears as several narrow, uniformly pigmented longitudinal bands that tend to occur on multiple nails at the same time. On dermoscopic examination, these bands usually show evenly spaced parallel lines with little or no variation in color, and Hutchinson's sign is generally not seen.[31] The combination of consistent coloration and involvement of multiple nails strongly suggests a medication-related origin.
- Trauma-related melanonychia, whether caused by subungual hemorrhage or repeated mechanical friction, typically produces areas of uniform brown to black discoloration. Dermoscopy may reveal well-defined globules or unevenly shaped blotches, and a gradual lightening of the pigment toward the distal nail edge is often seen as the trapped blood breaks down and the nail continues to grow.[29] In contrast to melanocytic lesions, these changes usually do not originate from the proximal matrix and lack the orderly linear pattern that characterizes true melanocytic bands.
- Onychocytic matricoma is an uncommon but benign tumor of the nail matrix that can, at first glance, be mistaken for melanoma. Dermoscopic examination, however, often reveals a well-defined and relatively unchanged longitudinal band, sometimes accompanied by thickening of the overlying nail plate. Importantly, features such as irregular pigmentation or atypical vascular patterns, which would raise concern for melanoma, are usually absent.[32] The preservation of orderly lines and the overall stability of the lesion with time are valuable clues that help distinguish it from malignant processes.

Taken together, these dermoscopic findings give clinicians a clearer sense of which cases of melanonychia are likely benign and which may warrant closer scrutiny, allowing many patients to avoid invasive testing when it is not necessary. Distinguishing tumoral lesions from non-neoplastic inflammatory conditions remains essential, as the management pathways diverge considerably. Subungual melanoma generally requires surgical treatment and further oncologic assessment, whereas most inflammatory or otherwise benign causes can be handled with conservative measures. Table 3 summarizes the principal clinical and dermoscopic characteristics that help separate tumoral etiologies from inflammatory sources of melanonychia.

Nail melanonychia from matrix melanocytes forms longitudinal pigment bands spanning the nail from proximal to distal. Dermoscopy can assist in inferring pigment origin; however, in thin fingernails or mixed patterns, localization is often challenging, and pigment may appear to involve both plate layers simultaneously. Consequently, dermoscopy complements—but does not replace—histopathology. Pigment deposition is in the upper part of the free edge of the plate, indicating that melanin originates from the proximal nail matrix. If it is in the lower part, it shows that melanin originates from the distal nail matrix. The evaluation of pigment origin has a specific guiding significance for selecting further biopsy techniques. By observing the background color of the melanonychia nail bands, it is possible to distinguish whether the lesion originates from the activation or proliferation of melanocytes in the nail matrix: a gray background

Table 3 Comparison Between Tumoral and Inflammatory Causes of Melanonychia

Feature	Tumoral Causes	Inflammatory Causes
Etiology	Melanocytic proliferation (benign or malignant)	Activation due to infection, inflammation, trauma, or drug exposure
Typical Onset	Gradual, persistent, may progress over time	Often acute or subacute; may be reversible
Number of Nails Involved	Usually single digit	Often multiple nails (except trauma/warts which may be single)
Pigment Band Appearance	Irregular borders, variable width and color	Homogeneous or regular bands, often brown/gray
Dermoscopy Features	Irregular parallel lines, Hutchinson's sign, triangular pattern	Regular lines, yellowish spikes (fungi), homogeneous fading (trauma), no Hutchinson's sign
Associated Nail Changes	Dystrophy, nail plate may destruction	Thickening (fungus), hemorrhage, wart surface disruption
Histopathology	Melanocytic hyperplasia or atypia	Nonspecific inflammation
Biopsy Required	Yes	Often not needed
Management Approach	Surgical excision, oncologic follow-up if malignant	Treat underlying cause: antifungals, trauma avoidance, cryotherapy, etc.

with or without gray regular lines indicates the activation of melanocytes in the nail matrix, while a brown background suggests the proliferation of melanocytes, which should be carefully distinguished between benign and malignant signs. If the pigment band is 3 mm or less, with or without brown/black parallel lines, and the width, spacing, and color of the lines are regular, it is primarily benign melanocytic proliferative diseases such as nail nevi and freckle-like nevi. Suppose the width of the melanonychia band is ≥ 5mm and/or irregular black lines, micro-Hutchinson's sign, and parallel ridge pattern of nail bed pigmentation appear.[33] In that case, the possibility of subungual melanoma should be suspected, and a histopathological examination should be performed to confirm the diagnosis. In addition, Hirata et al[34] proposed four dermoscopy patterns of nail matrix after observing 100 cases of longitudinal melanonychia:

- Regular gray band pattern (melanocyte activation)
- Regular brown band pattern (benign melanocytic hyperplasia)
- Regular brown band pattern with small balls/spots (melanocytic nevi)
- Irregular band pattern (nail melanoma)

It is important to note that the four patterns mentioned above may only be applicable in certain situations. For instance, melanocyte activation may result in regular brown band patterns in melanoma, while irregular band patterns appear in benign melanocytic nevi.

Indeed, observing melanonychia through dermoscopy has its limitations. Pigment bands observed during non-invasive dermoscopy are melanin deposition locations on the plate, not production locations. It is difficult to distinguish between gray and light brown background stripes, and there is subjectivity in judging line regularity. Pediatric melanonychia has adult melanoma-like manifestations, but the pathological results are mostly benign melanocytic proliferative diseases. Thus, adult dermoscopy criteria may not apply to children.[35] In short, a benign dermoscopic pattern does not rule out melanoma. Dermoscopy can guide diagnosis but cannot replace histopathology, which remains the definitive standard.

Reflectance confocal microscopy (RCM) is an advanced, non-invasive imaging technique that enables high-resolution scanning of skin layers from epidermis to dermis, facilitating the detection of pathological changes and improving the diagnostic accuracy of dermoscopically ambiguous lesions.[36] It is widely applied for diagnosis, evaluation of large lesions in cosmetically sensitive areas, guidance of targeted biopsies, preoperative margin delineation, assessment of treatment response, and surveillance for recurrence.[37] When performed prior to biopsy, RCM increases the reliability of histopathological sampling. In addition, real-time microscopic examination of freshly excised tissue has allowed integration of RCM into Mohs surgery for intraoperative margin assessment. RCM streamlines workflow by eliminating tissue processing and sectioning, reducing turnaround time by two-thirds, and enhancing the accuracy of distinguishing benign from malignant skin tumors, including melanocytic lesions, when combined with clinical and dermoscopic findings.[38] Compared with conventional biopsy, both dermoscopy and RCM are painless, repeatable, and dynamic methods for in vivo follow-up, offering patient comfort and high compliance. Beyond cutaneous tumors, RCM contributes to the early detection of subungual melanoma and enables longitudinal monitoring of nail lesions, thereby helping to reduce unnecessary resections. However, due to light scattering and the thickness of the nail plate, in vivo RCM has limited penetration and primarily visualizes pigment within the nail plate and superficial nail bed. Reliable assessment of matrix-level structures is generally feasible only ex vivo on freshly excised tissue or after partial plate removal.

Treatment of Nail Melanocytic Diseases

The treatment of melanonychia mainly targets the cause of the disease. Physiological melanonychia do not typically require treatment. Most cases of iatrogenic melanonychia can be resolved after removing the contributing factors. Skin lesions, systemic conditions, non-melanocytic nail tumors, and infections are managed by treating the underlying cause. Management of inflammatory and other non-melanocytic causes of melanonychia generally centers on addressing the underlying disorder, and most cases can be handled conservatively. Onychomycosis is treated with topical or systemic antifungal agents, with the choice guided by the extent of disease and whether the nail matrix is involved. Pigmentation

resulting from trauma, including subungual hemorrhage, often improves on its own once the mechanical insult has been removed. Medication-related pigmentation also tends to fade gradually after the causative drug is stopped, and no targeted therapy is usually needed. Subungual warts typically respond to cryotherapy or curettage, and associated pigmentary changes often clear as the lesion resolves. Onychocytic matricoma, though uncommon, may occasionally warrant a limited surgical excision when symptoms are present or a tissue diagnosis is required. Benign melanocytic lesions such as nail nevi or lentigines do not require active treatment; periodic monitoring is sufficient for most patients. For pathologically confirmed subungual melanoma, staging and grading based on Breslow depth, mitotic count, and presence or absence of ulcers are used to determine the appropriate treatment plan.[4]

In general, conservative surgical resection is performed for subungual melanoma with a Breslow depth of less than 0.5 mm, involving the removal of all nail attachments, including the nail matrix, bed, plate, and folds. After the surgery, a second-stage skin graft is usually performed to cover the defect and promote healing. However, complete removal during surgery is often impossible due to the proximity of the proximal nail matrix to its underlying bone surface and the extensor digitorum tendon. Therefore, some experts suggest simultaneously removing a small portion of the bone tissue on the finger or toe surface during surgery. Additionally, using conventional H&E staining sections instead of fast-frozen sections in slow Mohs microsurgery can better observe melanocytes, ensuring the removal of tumor tissue while preserving as much normal tissue as possible.[39]

The analysis of subungual melanoma treatment cases revealed that amputation did not bring more significant benefits to patients in terms of prognosis and survival rate. Conversely, conservative surgical treatment can better preserve the function of the affected limb without affecting prognosis.[40] Studies have explored conservative therapy for in situ or mildly invasive nail melanocytic diseases without metastasis, showing no recurrence after surgery. Furthermore, research indicates that if subungual melanoma is diagnosed early and undergoes appropriate resection surgery, in situ melanoma and stage I melanoma can be cured for life. In recent years, partial excision of the nail bed and nail matrix has been gradually adopted in clinical practice for nail melanocytic diseases, achieving sound therapeutic effects.

While partial matrix/bed excision guided by dermoscopy and, where available, intraoperative RCM may preserve nail anatomy in low-risk lesions, this strategy has limitations:

- Real-time margin assessment is imperfect because dermoscopy/RCM cannot reliably define deep and lateral tumor extent.
- Repeated limited excisions may delay definitive treatment if melanoma is present.
- There are theoretical concerns that repeated procedures might alter tumor biology.

Therefore, for clinically or dermoscopically suspicious lesions (eg, irregular or widening bands ≥5 mm, periungual extension/Hutchinson's sign, ulceration, rapid change); we favor complete excision with appropriate margins and permanent histology (slow Mohs or staged excision) over partial procedures. Partial excision should be reserved for lesions with very low malignant potential, following multidisciplinary discussion and informed patient consent.

Based on the characteristics of melanin that originate from the nail matrix, a thin excision of the diseased tissue during surgery preserves the remaining healthy nail matrix to produce a complete nail again, contributing to minimizing the risk of nail dystrophy. A recent study indicates that atypical melanocyte infiltration in the dermis under the nail matrix occurs later than in other nail tissues or only infiltrates a thin layer of dermal tissue.[41] This study supports conservative treatment of early-stage subungual melanoma patients and provides a basis for partial excision of the nail bed and nail matrix in patients suspected of malignant transformation of nail melanocytic disease. Nonetheless, during the surgical treatment of subungual melanoma, the following problems often occur:

- Lesion is clinically considered benign, leading to too small a resection and recurrence.
- Preoperative evaluation may underestimate extent of disease, preventing complete excision.
- Intraoperative findings may not match the initial diagnosis, forcing a change in surgical plan mid-procedure.

Dermatologists must consider and solve how to avoid secondary surgery or emergency changes in surgical methods caused by the above situations as much as possible.

Conclusion and Outlook

Accurately distinguishing melanonychia caused by tumors from that arising from benign conditions is essential, as delays in recognizing subungual melanoma can be serious, yet overly aggressive investigation in harmless cases should be avoided. Dermoscopy, used alongside a biopsy when indicated, continues to serve as the central tool in evaluation. Particular caution is warranted when a single nail in an adult is affected, since the likelihood of melanoma is greater in this group, whereas melanonychia in children is far more often benign and can usually be monitored without intervention. A familiarity with the dermoscopic appearances typical of fungal infection, trauma, medication effects, or viral lesions helps reduce unnecessary procedures and lowers the chance of misdiagnosis. Treatment should be directed by the specific etiology, whether that involves antifungal therapy, removing sources of repetitive trauma, or, in the case of certain benign tumors, a conservative surgical excision. Future efforts should focus on improving diagnostic accuracy through validated dermoscopic criteria, clinical scoring tools, and biomarker discovery to support risk stratification and individualized care.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors declare no conflicts of interest in this work.

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