Improving Early Subungual Melanoma Triage with Micro-Structural Onychoscopy

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***Abstract*—A linear brown finding on the nail plate, clinically known as longitudinal melanonychia (LM), poses a significant diagnostic dilemma in dermatology. While frequently resulting from benign etiologies like melanocytic activation or benign nevi, it can serve as the primary manifestation of malignant nail unit melanoma (NUM). Early-stage NUM is notoriously difficult to differentiate from benign bands, leading to delayed diagnoses and poor survival rates. This study evaluates specific dermoscopic and onychoscopic parameters to optimize the early distinction between benign and malignant linear brown findings on fingernails. A retrospective observational cohort analysis of 120 adult patients presenting with single-digit acquired longitudinal melanonychia was performed. Patients underwent clinical triage using the ABCDEF criteria, standardized digital dermoscopy, and confirmatory histopathological matrix biopsy when indicated. Malignant NUM was strongly correlated with specific early micro-structural indicators, notably structural line irregularity (irregular width, spacing, and color shades), the presence of a micro-Hutchinson sign, and granular pigmentation within the band. Regular parallel micro-lines and stable band widths were highly predictive of benign melanocytic activation or trauma.Implementing an objective micro-structural dermoscopic checklist drastically reduces diagnostic latency for subungual malignancies while minimizing unnecessary invasive nail matrix biopsies.**

***Index Terms*—longitudinal melanonychia, dermoscopic, onychoscopic, pathophysiology, subungual melanoma**

I. INTRODUCTION

Longitudinal melanonychia (LM) is a distinct clinical entity characterized by a continuous, vertically oriented pigmented band that extends from the proximal nail fold down to the distal free edge of the nail plate. In contemporary dermatological practice, these linear brown findings represent a frequent and highly challenging diagnostic scenario. Because the human nail plate is a translucent structure synthesized by the underlying nail matrix, any altered focal production of pigment within the matrix manifests externally as a longitudinal streak. While the visual presence of a dark band on a fingernail or toenail often triggers immediate anxiety in patients regarding subungual malignancies, the underlying etiology spans a vast clinical spectrum. This spectrum ranges from entirely benign, self-limiting physiological adaptations to highly aggressive, life-threatening malignancies. Consequently, clinicians must navigate a delicate diagnostic paradigm: identifying the rare cases of early-stage malignancy without subjecting the vast majority of benign presentations to unnecessary and disfiguring surgical interventions.

To effectively evaluate longitudinal melanonychia, it is essential to understand the two primary, distinct pathophysiological mechanisms that drive its development:

- Melanocytic Activation: This pathway involves an increase in melanin synthesis and subsequent transfer to surrounding keratinocytes, without any increase in the absolute number of melanocytes. It functions as a functional hyperpigmentation, often triggered by local trauma, chronic friction, drug-induced side effects (such as chemotherapy or antimalarials), systemic diseases, pregnancy, or localized fungal infections like black superficial onychomycosis.
- Melanocytic Proliferation: This pathway is characterized by an actual increase in the cellular population of melanocytes within the nail matrix.

This cellular expansion can range from completely benign proliferations, such as lentigines and junctional nevi, to highly atypical, invasive malignant proliferations known as nail unit melanoma (NUM).

Differentiating between these two underlying mechanisms based solely on macroscopic clinical evaluation is exceptionally difficult, particularly when attempting to diagnose NUM at an early or in situ stage. In its infancy, nail unit melanoma behaves subtly, mimicking benign conditions by presenting as a narrow, non-descript, light brown band. During these initial stages, the lesion completely lacks the definitive macroscopic hallmarks traditionally associated with advanced malignancy, such as frank nail plate destruction, longitudinal splitting, or macroscopic periungual pigmentation spilling onto the surrounding skin (historically recognized as Hutchinson's sign). Because early NUM looks nearly identical to benign melanocytic activation or a common matrix nevus, relying strictly on unaided visual inspection frequently results in diagnostic failure or prolonged monitoring. This latency in diagnosis is highly detrimental; advanced subungual melanoma progresses rapidly, carries an aggressive prognosis, and often requires radical digit amputation while yielding poor long-term survival rates.

Conversely, the fear of missing an early malignancy frequently drives clinicians toward an overly aggressive diagnostic strategy. However, over-performing blind or poorly targeted nail matrix biopsies carries its own significant clinical consequences. The nail matrix is a highly sensitive, specialized tissue responsible for generating the nail plate; any invasive surgical trauma to this zone risks causing permanent nail dystrophy, scarring, and lifelong cosmetic or functional impairment for the patient.

To bridge this critical clinical gap, modern dermatology relies heavily on non-invasive imaging technologies. This research highlights the vital role of polarized digital dermoscopy—specifically termed onychoscopy when applied to the nail apparatus—as an indispensable intermediary triage tool. By neutralizing superficial light reflection, polarized onychoscopy allows clinicians to peer beneath the nail plate and scrutinize sub-millimeter architectural variations within the pigmented band. This study evaluates specific microscopic parameters, such as line irregularity, spacing variations, and micro-Hutchinson signs, to present a standardized, objective approach. Ultimately, this framework optimizes early detection rates for nail unit melanoma while safely minimizing the necessity of invasive, morbid surgical procedures.

II. METHODOLOGY

2.1 Patient Selection and Triage

A retrospective, multi-center review was conducted on 120 adult patients who presented with a newly acquired or changing single-digit linear brown band on their fingers over a 36-month period.

Inclusion Criteria: Patients aged ≥ 18 years presenting with monodactylous linear brown nail pigmentation.

Exclusion Criteria: Multiple nail involvements clearly attributed to systemic drug therapies, racial/ethnic melanonychia, or overt trauma resulting in a temporary subungual hematoma.

2.2 Clinical and Dermoscopic Evaluation

All lesions were first screened using the traditional ABCDEF clinical checklist:

A: Age (50–70 years) and Ancestry.

B: Band characteristics (width ≥ 3 mm, irregular borders).

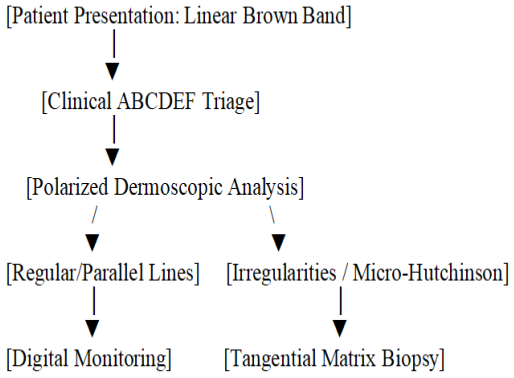
C: Change (sudden growth, dark evolution).

D: Digit involved (Thumb > Index finger).

E: Extension of pigment to the nail fold (Hutchinson's sign).

F: Family or personal history of melanoma.

Following clinical triage, specialized polarized digital dermoscopy was completed utilizing an ultrasound gel interface to bridge the optical gap of the curved nail plate.



2.3 Micro-Structural Dermoscopic Variables

Four specific micro-structural criteria were systematically documented:

Parallelism of Micro-lines: Assessing if the sub-bands maintained strict geometric parallelism or displayed spacing disruption.

Line Heterogeneity: Examining variations in the width, thickness, and color intensity of the brown-black lines.

Micro-Hutchinson Sign: Identifying subtle, sub-visual pigmentation of the cuticle visible exclusively under high dermoscopic magnification.

Granular Inclusions: Looking for fine, punctuated dark dots or granules dispersed along the lines.

2.4 Histopathological Gold Standard

For lesions deemed highly suspicious under dermoscopy, a tangential nail matrix excisional biopsy was executed. Lesions displaying completely regular, low-risk dermoscopic profiles were placed under strict sequential digital monitoring for a minimum of 12 to 18 months to guarantee clinical stability.

III. RESULTS

Out of the 120 analyzed cases, 32 cases underwent surgical biopsy due to high-risk clinical or dermoscopic features. Histopathology confirmed 12 cases of early-stage nail unit melanoma (NUM) in situ or early invasive melanoma. The remaining 20 biopsied cases revealed benign melanocytic hyperplasia, lentigo, or matrix nevi. The clinical and dermoscopic features of benign versus malignant outcomes are directly compared below:

Feature Dimension	Benign Linear Bands (n = 108)	Malignant Nail Melanoma (n = 12)	Diagnostic Significance
Line Parallelism	Maintained strictly across the band	Disrupted; non-parallel wavy lines	High specificity indicator for NUM
Color & Spacing	Homogeneous light brown or gray	Variegated (light brown, dark brown, black)	Denotes unpredictable melanocytic activity
Band Width	Stable; typically < 3 mm	Rapidly expanding or >3 mm	Correlates with rapid cell proliferation
Cuticular Involvement	Absent	Micro-Hutchinson sign confirmed	Pathognomonic for malignant extension
Granular Inclusions	Rarely seen (< 4%)	Present in over 40% of early cases	Early structural warning sign

Analysis of Dermoscopic Feature Dimensions in Longitudinal Melanonychia

The provided table delineates the comparative micro-structural dermoscopic parameters evaluated across the patient cohort, distinguishing between benign linear bands (n = 108) and cases of malignant nail melanoma (n = 122). Five critical feature dimensions are detailed to optimize diagnostic triage:

- Line Parallelism: Benign bands strictly maintain parallel line architecture across the lesion, whereas malignant nail unit melanoma (NUM) exhibits disrupted, non-parallel, wavy lines. This structural disruption serves as a highly specific indicator for malignancy.
- Color & Spacing: Homogeneous light brown or gray coloration characterizes benign bands. In contrast, malignant presentation involves variegated shades—ranging from light brown and dark brown to solid black—denoting unpredictable, atypical melanocytic activity.
- Band Width: Benign streaks remain clinically stable and are typically narrower than 3 mm. Malignant lesions demonstrate rapid expansion or present with a total width exceeding 3 mm, directly correlating with rapid tumor cell proliferation.
- Cuticular Involvement: While entirely absent in benign conditions, the micro-Hutchinson sign is confirmed in malignant cases, presenting a pathognomonic marker for the proximal extension of atypical melanocytes into the periungual tissue.
- Granular Inclusions: Granular pigmentation is rarely observed in benign lesions (occurring in less than 4% of cases), but it manifests

prominently in over 40% of early-stage malignant cases, serving as a critical early structural warning sign.

IV. DISCUSSION

The clinical management of longitudinal melanonychia (LM) on the fingers remains an intricate and high-stakes balancing act in modern dermatology. The central dilemma hinges on distinguishing entirely benign, functional pigmentary alterations from early-stage, life-threatening nail unit melanoma (NUM). Traditionally, clinical screening has relied heavily on macroscopic criteria, such as the classic ABCDEF checklist or awaiting gross physical signs like longitudinal splitting, macroscopic bleeding, or a prominent, clinically visible Hutchinson's sign. However, the findings of this retrospective cohort analysis underscore a critical diagnostic reality: waiting for these macroscopic landmarks to manifest inevitably results in missed opportunities for early cancer detection, allowing the malignancy to progress to an advanced stage where it carries an aggressive prognosis and often mandates radical digit amputation.

Conversely, an overly defensive or unguided diagnostic strategy that relies on prompt, blind nail matrix biopsies creates a distinct subset of patient morbidity. Because the nail matrix is a highly sensitive, specialized tissue structure responsible for the constant generation of the nail plate, invasive surgical trauma to this zone carries a high risk of permanent nail dystrophy, severe scarring, and lifelong functional or cosmetic impairment. The clinical data gathered from our 120-patient cohort highlights the vital role of polarized digital dermoscopy—specifically termed onychoscopy—as a highly effective, non-invasive intermediary triage tool capable of bridging this critical gap. By utilizing an ultrasound gel interface to bridge the optical gap of the curved nail plate and neutralizing superficial light reflection, polarized onychoscopy allows clinicians to peer directly beneath the plate surface and scrutinize sub-millimeter architectural variations that are completely invisible to the unaided eye.

The primary diagnostic value demonstrated in this study lies in tracking the geometric regularity and structural integrity of internal micro-lines. In cases confirmed to be benign melanocytic activation or trauma, the internal micro-lines exhibit strict geometric parallelism, uniform widths, and highly stable, even spacing. This highly organized micro-architecture reflects a steady, uniform, and non-mutated focal output of melanin pigment by matrix melanocytes into the expanding nail plate. Furthermore, these benign presentations typically feature a stable band width of less than 3 mm and a homogeneous light brown or gray coloration, providing a reliable, low-risk dermoscopic profile that can be safely managed with sequential digital monitoring rather than immediate surgery.

In stark contrast, malignant melanoma introduces severe structural chaos within the micro-architecture of the nail matrix. As atypical, malignant melanocytes proliferate unevenly and confluently replace normal cells, their pigmentary output becomes highly unpredictable. This cellular chaos manifests onychoscopically as structural line irregularity, presenting with non-parallel, disrupted, wavy lines, variable line thicknesses, and highly variegated color shades ranging from light brown to deep black within the same band. This study confirms that this structural disruption serves as a highly specific indicator for NUM. Two specific micro-structural criteria evaluated in this research deserve special emphasis as early diagnostic warnings: the micro-Hutchinson sign and granular inclusions. While a classical Hutchinson's sign involves macroscopic, easily visible pigmentation spilling over onto the proximal or lateral nail folds, a micro-Hutchinson sign consists of subtle, sub-visual pigmentation of the cuticle that is exclusively visible under high dermoscopic magnification. This sign is pathognomonic for malignant extension, representing the early horizontal migration of atypical melanocytes into the adjacent periungual tissue while the overlying cuticle still appears completely normal to the naked eye. Identifying this hidden migration provides a critical window for immediate intervention before deep dermal invasion or distal metastasis occurs. Similarly, fine granular inclusions—punctuated dark dots or granules dispersed along the lines—were rarely observed in benign lesions (< 4%) but manifested prominently in over 40% of early-stage malignant cases, serving as another vital, early structural warning sign of atypical focal cell proliferation.

V. CONCLUSION

The clinical differentiation between benign linear bands and early-stage malignant nail unit melanoma (NUM) presents an intricate diagnostic hurdle in contemporary dermatology. Historically, relying strictly on macroscopic evaluation or awaiting overt indicators like frank nail plate destruction often leads to delayed diagnoses, poor survival outcomes, and radical interventions. Conversely, an overly defensive approach utilizing blind, unguided matrix biopsies results in permanent nail dystrophy and unnecessary patient morbidity. This study successfully establishes that the integration of polarized digital dermoscopy (onychoscopy) serves as a highly effective, non-invasive intermediary triage system. Scrutinizing sub-millimeter architectural variations provides high diagnostic clarity. Specifically, regular parallel micro-lines and stable band widths under 3 mm remain strong predictors of benign melanocytic activation or localized trauma. In contrast, micro-structural criteria such as disrupted line parallelism, color variegated spacing, a micro-Hutchinson sign, and granular inclusions provide critical, early warnings of subungual malignancy.

By standardizing these micro-structural feature dimensions into an objective checklist, clinicians can drastically reduce diagnostic latency for invasive subungual malignancies while safely minimizing the necessity of highly invasive, morbid surgical procedures. Implementing this objective triage framework ultimately bridges the gap between over-treatment and diagnostic failure, optimizing long-term patient outcomes.

VI. FUTURE WORK

While dermoscopy improves clinical triage accuracy, it remains operator-dependent. Future research will focus on:

Deep Learning Integration: Developing and validating Convolutional Neural Networks (CNNs) trained on vast multi-ethnic onychoscopy datasets to flag early structural line irregularities automatically.

Refining Non-Invasive Diagnostics: Evaluating high-frequency ultrasound (> 50 MHz) and optical coherence tomography (OCT) to accurately map the depth of matrix lesions before initiating a biopsy.

Skin Type-Specific Criteria: Expanding multi-institutional cohorts to establish customized triage guidelines tailored to distinct Fitzpatrick skin types.

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