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Standardizing Pigment-Specific Dermoscopic and AI-Based Diagnostic Tools to Address Racial Disparities in Dermatology

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ABSTRACT

Standardizing pigment-specific dermoscopic and AI-based diagnostic tools offers a transformative approach to addressing racial disparities in dermatology, particularly in the accurate diagnosis and management of pigmentary skin conditions. Traditional dermatological diagnostic methods, which often rely on visual assessments, are frequently less effective for individuals with darker skin tones due to the challenges posed by pigmentation variations, making it difficult to detect subtle changes in lesions that may indicate malignancy or progression. Advanced dermoscopy techniques, specifically designed to identify pigmentary changes in skin of color, are now integrated with artificial intelligence, enhancing both diagnostic precision and efficiency. AI-driven algorithms, trained on large, diverse datasets that accurately reflect a range of skin tones, enable superior lesion detection, classification, and risk stratification, particularly for conditions such as melanoma, basal cell carcinoma, and other pigmented lesions. The integration of high-resolution dermoscopic imaging with AI tools allows for the identification of features that might otherwise remain undetected, such as nuanced changes in color, shape, and texture of lesions in darker skin. Standardizing these technologies ensures their consistent, reliable application across clinical environments, making them effective for diverse patient populations. By incorporating pigment-specific dermoscopy and AI into dermatology practice, healthcare providers can significantly enhance

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diagnostic accuracy, reduce the incidence of misdiagnoses, and address the challenge of late-stage diagnoses, which are disproportionately prevalent in racially diverse populations. Integrating AI-based tools into medical education and clinical practice supports more equitable care, equipping dermatologists with the decision-making capabilities needed to provide optimal, individualized treatment, and ultimately reducing health disparities within dermatology.

Keywords: Skin of Color, Dermatology, Artificial Intelligence, Dermatologic Care.

INTRODUCTION

Racial disparities in dermatologic care are well-documented, with significant differences in access to services, disease prevalence, and treatment outcomes among various racial and ethnic groups. These disparities stem from factors such as socioeconomic barriers, implicit bias, and gaps in medical education regarding skin of color (SOC), leading to delayed diagnoses and poorer outcomes for conditions like melanoma, which is often diagnosed at later stages in individuals with darker skin tones [1]. Traditional dermatologic diagnostic methods rely heavily on visual assessments. However, for patients with SOC, pigmentation variations can obscure subtle changes in lesions, rendering these conventional techniques less effective. In response, advanced diagnostic tools—such as dermoscopy and artificial intelligence (AI) algorithms — have been developed. Dermoscopy enhances visualization of subsurface skin structures, while AI models, when trained on diverse datasets, can improve lesion detection and classification accuracy. Despite these advancements, challenges remain, including the underrepresentation of SOC in training datasets and the need for high-quality, standardized imaging protocols [2,3]. The integration of standardized pigment-specific dermoscopic techniques and AI-based tools presents a promising strategy to enhance diagnostic precision and ensure equitable care across diverse populations. By incorporating these advanced technologies into clinical practice, healthcare providers have the potential to reduce misdiagnoses and mitigate the problem of late-stage detection, which disproportionately impacts racially diverse patient groups [4,5]. This approach not only supports more equitable care but also empowers dermatologists with improved decision-making tools for optimal, individualized treatment.

This literature review aims to provide an updated overview of dermoscopy techniques and AI tools that offer improved diagnostic accuracy for skin of color. Moreover, it seeks to establish a framework for integrating these novel technologies into routine clinical practice. By examining recent advancements and identifying continuing challenges, the review advocates for the standardization of pigment-specific diagnostic tools as a means to reduce racial disparities in dermatology.

REVIEW

DIAGNOSTIC GAP

TThe diagnostic gap in skin of color (SOC) is a significant issue in dermatology, stemming from a historical underrepresentation of darker skin tones in medical education and clinical research. This has led to a lack of familiarity and confidence among clinicians when diagnosing dermatologic conditions in SOC, a concern highlighted by the American Academy of Dermatology [6]. According to various studies, the disproportionately low representation of SOC dermatology in the medical education system of the United States contributes directly to adverse experiences and health inequities for individuals of color [6]. These foundational gaps in training and resources result in a critical disparity where patients are more likely to receive missed or delayed diagnoses.

Visual diagnosis in pigmented skin presents unique challenges that can impede accurate and timely care. Inflammation, for instance, may not exhibit the typical erythema seen in lighter skin, making it harder to identify conditions such as psoriasis or atopic dermatitis [7]. This difficulty can result in delayed or missed diagnoses, contributing to poorer health outcomes for SOC patients [8]. Research confirms this disparity, showing that dermatologists are significantly more likely to correctly identify skin diseases through visual diagnostics in patients with lighter skin. One study found that dermatologists correctly identified diseases in 72.1% of lighter skin cases compared to only 52.8% in SOC cases [9]. These findings underscore how the different clinical presentations in pigmented skin create a substantial barrier to effective visual diagnosis.

The consequences of these diagnostic limitations are profound, leading to severe and inequitable clinical outcomes. Patients with SOC often face an increased risk of late-stage diagnoses for critical conditions like melanoma, which is associated with worse survival rates compared to lighter-skinned individuals

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[10]. For example, melanoma is diagnosed at a later stage in 52% of SOC patients, while the same is true for only 16% of lighter-skinned patients [11]. Furthermore, higher rates of misdiagnosis and undertreatment are common, as clinicians may not recognize or appropriately treat conditions that present differently in SOC [12]. A study on melanoma diagnosis revealed misdiagnosis rates in Black patients were 62% and 31% for two different images, respectively, compared to just 13% and 7% in white patients [13]. Ultimately, these diagnostic failures directly translate into a greater burden of disease and increased mortality for patients with skin of color.

These diagnostic challenges are a major contributor to systemic inequities in health outcomes and access to care. Patients with SOC are more likely to experience health disparities rooted in systemic racism, socioeconomic barriers, and critical gaps in physician training [10]. In response, the American Academy of Dermatology emphasizes the need for comprehensive education and training in SOC dermatology to address these disparities and improve care quality [1]. Efforts to diversify dermatologic education and research are therefore crucial to bridging this diagnostic gap and ensuring equitable healthcare for all patients, regardless of skin color [6]. Addressing the historical and systemic deficiencies in medical education regarding skin of color is the essential pathway to overcoming diagnostic disparities and achieving true health equity in dermatology.

ROLE OF PIGMENT-SPECIFIC DERMOSCOPY

Dermoscopy is a non-invasive diagnostic tool that significantly enhances the visualization of subsurface skin structures not visible to the naked eye. By revealing specific dermoscopic structures that correlate with histopathologic features [3], this technique improves the detection of skin cancers such as melanoma and basal cell carcinoma. Its fundamental purpose is to increase diagnostic accuracy for a wide variety of skin conditions beyond what can be achieved with a simple clinical examination.

Because skin conditions can present uniquely in darker skin tones, specific adaptations in dermoscopy are necessary to maintain diagnostic accuracy. The International Dermoscopy Society has validated additional criteria specifically for skin of color (SOC), including features like perifollicular scales and eccrine pigmentation [3]. Integrating these adaptations helps clinicians more effectively differentiate benign from malignant lesions, thereby addressing the distinct diagnostic challenges posed by variations in pigmentation.

Detecting pigmentary changes specific to darker skin requires recognizing unique patterns, such as the reticular pattern with central hyperpigmentation, which is more commonly found in the melanocytic nevi of individuals with skin types V and VI [16]. Mastering these adaptations allows clinicians to more accurately identify and differentiate various pigmentary disorders, like melasma and post-inflammatory hyperpigmentation, which can often be clinically challenging to diagnose in SOC [14]. To further refine diagnosis in SOC, enhancing the visibility of lesion characteristics can be achieved by using specific technologies like polarized light dermoscopy. This method reduces surface reflection and better highlights deeper pigmentation and vascular structures [17]. This improved visualization is particularly useful for identifying subtle changes in pigmented lesions, ultimately leading to greater diagnostic accuracy and better patient outcomes.

The clinical application of these adapted techniques is critical for identifying malignancies and other lesions in SOC. For melanoma, dermoscopic features such as an atypical network and blue-white veils are key indicators [18], while basal cell carcinoma often presents with arborizing vessels and blue-gray ovoid nests. Dermoscopy also aids in diagnosing other common lesions like seborrheic keratoses and dermatofibromas by revealing their own characteristic features [19]. Therefore, training physicians to recognize these pigment-specific patterns and utilize adapted dermoscopic techniques is essential for improving the early and accurate diagnosis of skin conditions in SOC and reducing disparities in dermatologic care.

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Figure 1. Dermoscopy Adaptations for Skin of Color

Aspect	Description	Key Benefits
Additional Dermoscopic Criteria	Perifollicular scales and eccrine pigmentation validated by the International Dermoscopy Society	Improves differentiation between benign and malignant lesions
Pigmentary Pattern Recognition	Identifying reticular patterns with central hyperpigmentation common in skin types V and VI	Enhances the detection of disorders like melasma and post-inflammatory hyperpigmentation
Polarized Light Dermoscopy	Reduces surface reflection and highlights deeper pigmentation and vascular structures	Facilitates identification of subtle changes in pigmented lesions
Clinical Application	Recognition of distinct patterns, such as atypical networks (melanoma) and arborizing vessels (basal cell carcinoma)	Improves diagnostic accuracy for skin cancers and other lesions
Physician Training	Education on pigment-specific adaptations and techniques	Enhances early detection and reduces disparities in dermatologic care

LEVERAGING AI IN DERMATOLOGY

Advancements in Dermatologic Image Analysis

Artificial intelligence (AI) has revolutionized image analysis and classification in dermatology through the application of technologies such as machine learning, deep learning, and convolutional neural networks (CNNs). These systems, trained on extensive image datasets, exhibit remarkable capability in identifying intricate patterns and features of various skin lesions [20]. By analyzing these datasets, AI models can discern subtle variations in lesion characteristics, including size, texture, and color, details that often escape the human eye [21]. This technological advancement significantly enhances the precision and efficiency of dermatologic diagnoses, thereby improving patient outcomes. Among these innovations, CNNs have emerged as a cornerstone for the automated interpretation of dermatologic images. Designed to process input data through interconnected nodes or artificial neurons, CNNs function through layers that collectively extract and classify image features [21]. When trained on comprehensive datasets encompassing dermoscopic, clinical, and histopathological images, these networks demonstrate a high degree of accuracy in distinguishing between benign and malignant lesions [21]. While AI systems are not intended to replace clinical judgment, they serve as indispensable tools that supplement dermatologists' diagnostic decision-making processes and optimize workflow efficiency.

Addressing Disparities in AI Diagnostic Accuracy

A significant limitation of artificial intelligence in dermatology lies in its reduced diagnostic accuracy for individuals with skin of color (SOC), primarily due to an underrepresentation of diverse skin tones in training datasets. This lack of inclusivity has led to a noticeable decline in the reliability of AI algorithms when applied to darker skin types compared to lighter ones. Studies evaluating AI systems such as ModelDerm, DeepDerm, and HAM100000 have highlighted this disparity. While these models performed effectively on their original training datasets, their accuracy diminished significantly when tested on more diverse dermatologic image (DDI) datasets [22]. In particular, diagnostic accuracy was consistently higher for lighter skin tones (Fitzpatrick types I–II) compared to darker tones (Fitzpatrick types V–VI) [22]. For instance, analysis of Skin Image Search, an AI-based dermatologic diagnostic tool, revealed a stark contrast in its performance: a mere 17% diagnostic accuracy for individuals with Fitzpatrick skin type VI, in comparison to a 69.9% accuracy rate for those with lighter skin [23]. This disparity underscores the urgent necessity of increasing diversity in AI training datasets to improve diagnostic outcomes for patients with darker skin tones. Despite the relatively lower prevalence of skin cancer among individuals with skin of color, these patients are often diagnosed at later stages, contributing to heightened morbidity, mortality, and healthcare costs [24]. Enhancing dataset representation is, therefore, essential to ensuring equitable and effective diagnostic capabilities across all demographics.

The Synergy of Artificial Intelligence and Dermoscopy

The integration of artificial intelligence with dermoscopy has substantially improved the detection and classification of skin lesions, resulting in higher diagnostic accuracy and

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better clinical outcomes. Dermatoscopes, when paired with AI systems, allow dermatologists to correlate magnified images of lesions with their exact locations on a 3D body map, thereby streamlining documentation and diagnosis [21]. For example, hybrid convolutional neural network (CNN) models have demonstrated exceptional performance, achieving accuracy rates of up to 97.7%, with sensitivity at 91.93% and specificity reaching 99.49% for differentiating malignant from benign lesions [25]. Real-world clinical studies further validate the utility of AI-assisted dermoscopy. One such study assessed the effect of a digital dermoscopy image-based AI algorithm (DDI-AI device) on dermatologists' diagnostic performance [Witkowski et al., 2024]. The findings revealed that the use of the DDI-AI device increased diagnostic sensitivity to 86.1%, compared to 78.8% with digital dermoscopy alone and 63.4% with standard clinical images. Similarly, diagnostic specificity improved to 80.7% with the DDI-AI device, as opposed to 75.9% and 73.6% for the other methods [26]. These results demonstrate how the combination of AI and dermoscopy serves as an invaluable adjunct in diagnosing skin cancers. This synergy not only enhances diagnostic precision but also facilitates earlier detection, more informed clinical decisions, and ultimately improved patient outcomes.

STANDARDIZATION ACROSS CLINICAL ENVIRONMENTS

For the effective integration of artificial intelligence (AI) into dermatology workflows, it is imperative to standardize implementation protocols, ensure consistent diagnostic accuracy, and address barriers to clinical adoption. A critical requirement for achieving generalizability is the establishment of standardized image acquisition practices within clinical settings. Key variables, including image blurriness, magnification, angle, lighting, and background, significantly impact the diagnostic performance of AI systems [27. For example, studies have demonstrated that elements such as surgical markings and poor image focus can adversely affect AI interpretation accuracy [27,28].

Despite its growing utility, AI cannot replace the comprehensive diagnostic processes employed by dermatologists. Essential findings from physical examinations, such as Darier's sign or buttonhole sign, as well as insights from histopathological analyses, remain beyond the current capabilities of AI systems [27]. While AI serves as a valuable adjunct in lesion assessment, it cannot fully replicate the multi-modal approach required for a definitive diagnosis, underscoring the continued necessity of human oversight in clinical decision-making.

Another significant limitation of AI systems is their interpretability. Deep learning algorithms are often described as "black box" systems due to their inability to provide clear explanations for their conclusions. This lack of transparency can result in hesitancy among clinicians, who bear ultimate responsibility for clinical outcomes [29,30]. To address this issue, enhanced collaboration between clinicians and data scientists is essential. Such collaboration would facilitate the integration of evidence-based medicine into AI decision-making processes and involve joint efforts in data collection, algorithm development, and the implementation of systems designed to improve diagnostic accuracy and to focus on the establishment of standardized practices, the thoughtful integration of AI into clinical workflows, and the development of transparent, explainable decision-making processes that inspire confidence among both clinicians and patients.

Addressing these limitations is essential to ensuring the safe, effective, and equitable application of AI in clinical dermatology. Future research efforts should prioritize the validation of AI tools through clinical trials in real-world practice, while actively working to overcome the aforementioned challenges.

OPPORTUNITIES FOR AI IMPLEMENTATION IN DERMATOLOGIC CARE

The integration of AI in dermatology presents numerous transformative opportunities to address longstanding healthcare disparities. AI-enhanced dermoscopy systems offer powerful solutions to overcome traditional diagnostic limitations [31], particularly benefiting skin of color (SOC) patients who have historically faced disproportionate healthcare burdens [32]. Primary opportunities include enhanced diagnostic accuracy through objective analysis and superior pattern recognition capabilities, especially valuable given that current dermatologists report significant gaps in SOC training [32,33]. AI systems can serve as educational tools, addressing the stark underrepresentation of diverse skin types in medical education materials, where only 4.55% of textbook images represent darker skin tones [32]. The technology offers particular promise in expanding healthcare access through telemedicine capabilities and improved triage systems [31], potentially compensating for the limited diversity in the dermatology workforce, which currently includes only 3.4% Black and 4.4% Hispanic/Latinx dermatologists [34]. Implementation opportunities extend to standardizing diagnostic protocols [35], creating inclusive training datasets [36], and developing transparent AI systems

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[37]. Public health institutions can leverage AI to ensure regulatory compliance and promote equity in healthcare delivery [38], while specifically addressing algorithmic bias through diverse dataset representation [39, 40]. Additionally, AI presents opportunities for continuous learning and improvement in diagnostic accuracy [41] while addressing patient concerns through transparent and accountable systems [42]. These technological advancements could revolutionize dermatologic care delivery, creating a more equitable healthcare system that serves all patients effectively, regardless of their skin color.

POLICY AND PUBLIC HEALTH CONSIDERATIONS

Artificial Intelligence (AI) represents a revolutionary force in public health, offering unprecedented capabilities to transform healthcare delivery. It can rapidly analyze complex datasets, provide personalized patient recommendations, and enhance decision-making support for clinicians [38]. The technology's ability to streamline traditionally time-consuming activities, from disease surveillance to routine administrative tasks, has captured global attention. Ultimately, this allows healthcare professionals to shift their focus from logistical burdens to more strategic public health initiatives and program implementation.

However, this technological advancement brings significant challenges, particularly regarding health equity. A critical concern centers on how AI will affect diverse and marginalized populations who already experience systemic healthcare disparities. Improperly designed or intrinsically biased AI systems risk perpetuating these inequities through biases related to race, gender, and socioeconomic status [39]. This danger is not merely theoretical; it is notably evident in fields like dermatology, where AI systems trained on limited datasets have already demonstrated reduced accuracy in diagnosing skin conditions in patients with darker skin tones [39]. Without intentional and careful design, AI technologies could amplify rather than remedy existing healthcare inequalities.

CURRENT INITIATIVES AND SOLUTIONS

Encouragingly, initiatives addressing these disparities are emerging across the healthcare sector. These include enhanced healthcare professional education, expanded research in skin of color dermatology, and efforts to increase workforce diversity [43]. Public health institutions are taking a leading role by:

1. Maintaining regulatory compliance
2. Prioritizing equity in AI design
3. Establishing robust data governance
4. Promoting ethical guidelines aligned with human rights

As AI integration accelerates in healthcare systems worldwide, careful stewardship becomes essential. Success requires balancing technological advancement with equity considerations, ensuring this powerful tool enhances rather than hinders healthcare accessibility and quality for all populations [38]. This balanced approach will be crucial in realizing AI's full potential while maintaining a commitment to equitable healthcare delivery.

CHALLENGES AND FUTURE DIRECTIONS IN AI-DRIVEN HEALTHCARE

While AI in healthcare has demonstrated remarkable potential to enhance diagnostic accuracy and personalize treatment, its successful implementation faces critical challenges. Algorithmic bias represents a primary concern, where systematic errors in machine learning can produce discriminatory outcomes based on race, culture, gender, or social status [44]. Patient focus groups have underscored these fears, revealing concerns that AI tools might reinforce existing healthcare biases through flawed datasets or unconscious developer prejudices [45]. To combat this, experts argue that AI systems must be trained using diverse, representative datasets and be regularly adjusted to reflect varied patient demographics [46]. Therefore, preventing the amplification of existing health disparities requires a proactive and meticulous approach to data handling and algorithm design.

Transparency emerges as another crucial challenge, as many complex AI systems operate as "black boxes" with opaque decision-making processes. Advocates for ethical AI design call for explainable systems that allow users to understand and, when necessary, challenge AI-driven decisions [47]. According to Subías-Beltrán et al. (2024), this transparency is essential for building trust among both healthcare providers and patients and ensuring equitable access to services. Alongside transparency, privacy requires careful consideration due to the sensitive nature of medical data, leading to the development of sophisticated technologies like blockchain, Federated Learning, and Homomorphic Encryption to maintain confidentiality [46]. Addressing these intertwined

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issues of transparency and privacy is fundamental to fostering the trust required for AI's widespread and ethical adoption in medicine.

The potential impact of AI is particularly promising in low-resource settings, where successful implementations like India's eSanjeevani telemedicine platform and AI-powered mobile health platforms in rural Africa have already been demonstrated [35]. However, significant hurdles such as infrastructure limitations, low technology literacy, and inadequate policy frameworks must first be overcome [48]. Moving forward, research priorities must focus on developing tools to combat algorithmic bias, understanding diverse patient perspectives, and evaluating AI implementation in these resource-limited environments. A comprehensive approach that prioritizes equity is therefore crucial for realizing AI's potential to improve healthcare access and outcomes for all populations, not just those in affluent regions.

CONCLUSION

Significant racial disparities in dermatologic care are perpetuated by a persistent diagnostic gap for patients with skin of color. Traditional visual assessment methods often fall short in pigmented skin, leading to delayed diagnoses and poorer outcomes, particularly for serious conditions like melanoma. As this review has detailed, the integration of advanced technologies, namely pigment-specific dermoscopy and artificial intelligence, offers a powerful strategy to overcome these historical limitations. Dermoscopy provides enhanced visualization of subsurface skin structures, while AI, when properly trained, can identify complex patterns that may elude the human eye. However, realizing this potential requires overcoming significant hurdles, particularly the algorithmic bias and lack of transparency that can perpetuate the very inequities these tools are meant to solve. A concerted effort, built on deep collaboration between clinicians and data scientists, is therefore essential. By embracing these technologies with a focus on equitable design, standardized implementation, and transparent decision-making, the field of dermatology can finally dismantle long-standing diagnostic barriers and build a future where all patients, regardless of skin color, receive timely, accurate, and truly just care.

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CONFLICT OF INTEREST

The authors declare no conflict of interest related to this manuscript.

CONCLUSION

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