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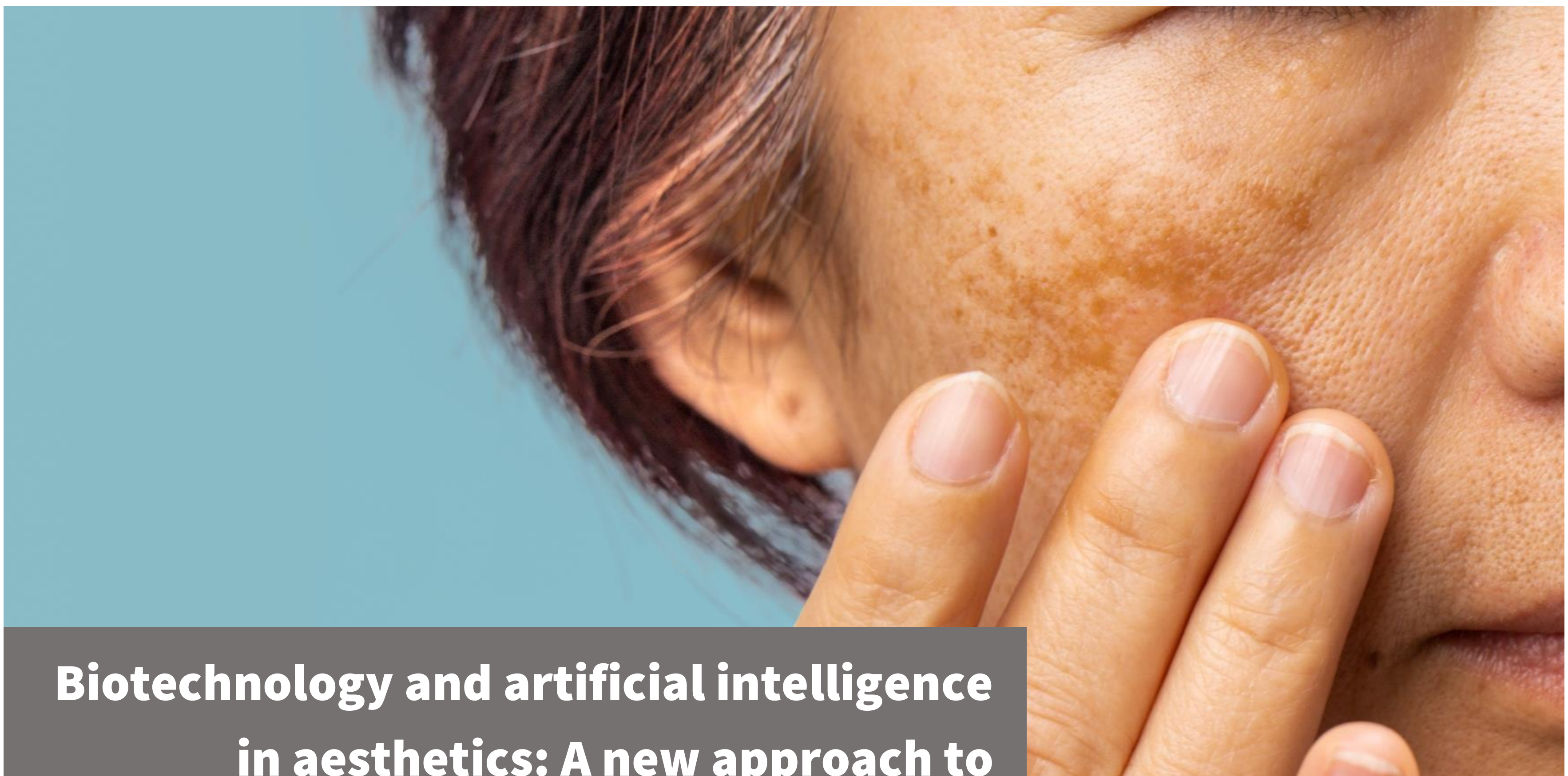

Biotechnology and artificial intelligence in aesthetics: A new approach to melasma diagnosis

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The diagnosis of melasma remains a clinical challenge due to its multifactorial nature and the subjectivity involved in visual assessment. Recent advancements in artificial intelligence (AI) and biotechnology have introduced new strategies for standardizing diagnosis, reducing interobserver variability, and optimizing treatment pathways. This article explores how AI, when integrated with biotechnology, provides a reliable and objective tool for diagnosing hyperpigmentary disorders. A novel case is presented using an AI-driven platform developed in Brazil, which utilizes image processing to calculate the Melasma Area and Severity Index (MASI), offering greater accuracy and reproducibility. The integration of such systems marks a new era in aesthetic diagnostics, promoting ethical, precise, and accessible interventions.

Keywords: Artificial intelligence, melasma, biotechnology, hyperpigmentation, aesthetic diagnosis, MASI, digital health.

Introduction

Melasma is a chronic acquired hyperpigmentary disorder presenting as irregu-lar brownish patches found primarily on the sun-exposed areas of the face. It primarily impacts women with darker skin types (Fitzpatrick III–V), and prevalence can be over 40% in some ge-ographies with a high level of UV exposure (Aamir et al., 2021). Melasma is not just cosmetic because it can have a great psychosocial impact, resulting in poor self-esteem and diminished quality of life (Deshpande et al., 2020).

The pathogenesis of melasma is multifactorial and is determined by complex interactions between genetic factors, hormone influences, photodamage, and inflammation (Kang & Ortonne, 2010). The diagnosis of melasma is traditionally based on visual inspection, Wood's lamp evaluation, and dermatoscopy; however, these aspects are somewhat subjective and operator dependent, which can limit valid diagnostic interpretations and effective treatment (Miot et al., 2009).

Meanwhile, Artificial Intelligence (AI) has recently become a disruptive technology within healthcare, with over 500 AI-enabled medical devices being approved by the FDA since 2016 (Benjamens et al., 2020). In dermatology, models trained with large datasets of images have demonstrated excellent performance at identifying, segmenting, and quantifying skin lesions. AI tools present a chance to standardize the diagnosis of melasma by offering more objective and reproducible data to report, like the Melasma Area and Severity Index (MASI) score, that can assist with more effective clinical monitoring of response to treatment and specialty referrals and personalized intervention.

The Diagnostic Challenge of Melasma

Melasma diagnosis remains a significant clinical challenge due to its complex pathophysiology and the lack of standardized diagnostic tools. Traditional evaluation relies primarily on naked-eye inspection, dermoscopy, and Wood's lamp examination, all of which are highly dependent on the clinician's experience, the patient's skin phototype, and lighting conditions (Miot et al., 2009). These methods offer only superficial information and cannot quantify pigment depth or distinguish between epidermal, dermal, or mixed patterns with high precision (Kang & Ortonne, 2010).

Histologically, melasma is characterized by increased epidermal and/or dermal melanogenesis, melanocyte hypertrophy, solar lastosis, inflammatory infiltrates, and disruption of the basement membrane (Schlessinger

Method	Technique	Strengths	Limitations	Reproducibility
Clinical Examination	Visual grading, MASI	Easy, low-cost, widely used	Highly subjective, lighting dependent	Low (ICC ~ 0.6–0.7)
Dermoscopy	Polarized imaging	Better lesion contrast, visualization of patterns	Requires training, lacks quantification	Moderate
Wood's Lamp	UV fluorescence	Distinguishes epidermal vs dermal pigmentation	Not reliable in darker skin types (Fitzpatrick IV–VI)	Low
Reflectance Confocal Microscopy (RCM)	Near-infrared imaging	High-resolution, cellular-level imaging	Expensive, limited availability	High, but not standardized
Skin Biopsy	Histopathological exam	Gold standard for histology	Invasive, not practical in aesthetics	High
AI-based Image Analysis	Deep learning algorithms	Objective, scalable, real-time evaluation	Requires validated datasets, regulatory approval	Potentially very high

Comparative Analysis of Diagnostic Methods in Melasma

As shown in Table, traditional diagnostic methods for melasma—such as clinical examination, dermoscopy, and Wood's lamp—are accessible but highly subjective and limited in accuracy, especially in darker skin types. Advanced tools like confocal microscopy and biopsy offer precision but are invasive or costly. AI-based image analysis stands out for combining objectivity, reproducibility, and non-invasiveness, addressing critical gaps in current diagnostic practice and enabling standardized, technology-driven assessment.

et al., 2021). However, such findings are only accessible through invasive biopsy and are not routinely used in clinical practice, especially in aesthetic dermatology settings.

Another significant obstacle is the interobserver variability in melasma severity grading. Clinical scoring systems, such as the Melasma Area and Severity Index (MASI) and its variations (modified MASI, mMASI), are widely used in clinical trials, but remain subjective and operator-dependent (Pandya et al., 2011). Variations in MASI scores between different evaluators can lead to misclassification of severity and inconsistent treatment responses.

Recent studies highlight that even among trained dermatologists, inter-rater agreement on melasma classification is often below 70%, and the intraclass correlation coefficient (ICC) for MASI scoring ranges from 0.61 to 0.72—indicating moderate agreement at best (Sheth et al., 2020). Such limitations hinder not only research standardization but also real-world treatment outcomes and patient satisfaction.

Therefore, objective, reproducible, and non-invasive diagnostic tools are urgently needed to assist in the classification, monitoring, and longitudinal follow-up of melasma. Digital imaging, spectroscopy, confocal microscopy, and more recently, artificial intelligence–based models offer promising avenues to address these limitations.

AI and Deep Learning applications in dermatological diagnosis

Recent developments in AI, particularly in deep learning, have introduced computer vision models trained on large datasets of annotated skin images. These systems can identify, segment, and classify skin lesions with accuracy comparable to or exceeding that of dermatologists.

In the context of melasma, AI tools are being developed to automate the identification of hyperpigmented areas and calculate the MASI score. One such example is a platform developed by the Brazilian startup Hoope Diagnostic, which employs AI-based image analysis to detect melasma patterns from smartphone photographs. This tool offers real-time diagnostic feedback, standardizes MASI calculation, and introduces the possibility of remote diagnostics and monitoring.

Unlike traditional methods, which require subjective assessment, the AI-driven approach ensures reproducibility by processing pixel-level data and applying standardized thresholds for pigmentation intensity and distribution. Additionally, such systems can be integrated with cloud-based data storage and analytics, enabling longitudinal tracking of disease progression and response to treatment.

Recent studies have demonstrated that AI models trained on dermatological datasets can achieve sensitivity and specificity above 90% in the classification of pigmented lesions, including melasma, when validated against expert consensus (Liu et al., 2023). These systems not only enhance diagnostic precision but also reduce interobserver variability, which is essential for consistent evaluation in both clinical practice and multicenter trials. Additionally, the ability to analyze images acquired from accessible devices democratizes dermatological care particularly in resource-limited or geographically remote settings. As AI technologies continue to evolve, their integration into aesthetic dermatology workflows may establish a new standard of care—objective, scalable, and patient-centered.

Validation, Limitations, and Future prospects

For AI-driven diagnostic systems to be clinically adopted, rigorous validation is essential. Comparative studies must evaluate metrics such as sensitivity, specificity, accuracy, and interobserver concordance with dermatologists. Studies like those by Liu et al. (2023) and Liopyris et al. (2022) provide frameworks for evaluating diagnostic AI tools, emphasizing transparency and external validation.

Although AI offers objectivity, challenges remain, including data bias, patient diversity, and regulatory acceptance. Datasets used for training must represent a wide range of skin tones, lesion types, and environmental conditions to ensure generalizability. Moreover, AI cannot yet fully substitute clinical judgment, particularly in complex or atypical cases.

Future perspectives involve the integration of AI with wearable devices, real-time diagnostics, and personalized treatment algorithms. The synergy between biotechnology and AI opens the door to biointelligent aesthetic medicine, where treatment is not only precise but dynamically responsive to patient-specific factors.

Conclusion

Artificial intelligence represents more than a future promise, it is already a transformative reality in the diagnosis and management of melasma. By overcoming the intrinsic limitations of traditional assessment methods, AI enables enhanced diagnostic precision, objective monitoring, and tailored treatment strategies. Tools such as the Hoope Diagnostic platform illustrate how the integration of biotechnology and machine learning can democratize access to high-quality dermatological evaluation, even in remote or underserved areas.

Rather than being a distant innovation, AI is now integrated into clinical routines, research environments, and digital health platforms. Its scalability, reproducibility, and data-driven nature not only streamline care delivery but also promote ethical and evidence-based decision-making. This convergence of science and technology marks a turning point in clinical practice, where diagnostic processes are no longer based solely on human perception but are enhanced by intelligent systems capable of continuous learning and adaptation.

To fully realize the benefits of these advances, ongoing investment in clinical validation, professional training, and interdisciplinary cooperation is essential. Equally important is ensuring that these technologies remain accessible and inclusive, avoiding the creation of new disparities in care. As we move into a new era of precision aesthetics, the integration of artificial intelligence and biotechnology is no longer a vision for the future, it is a clinical and ethical imperative of the present.

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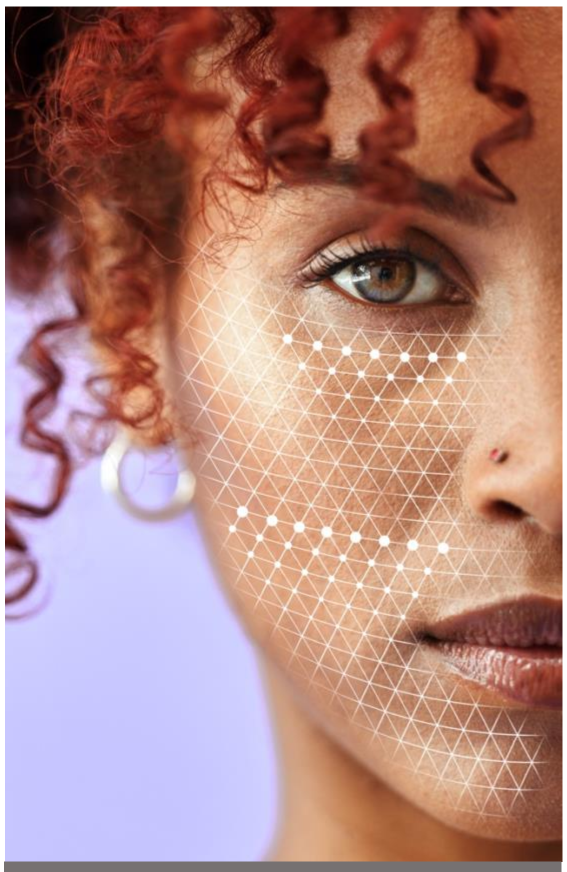

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