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A Comprehensive Review on Using Artificial Intelligence and Deep Learning to Predict Anemia in Humans

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Abstract

Anemia, a global health concern affecting over 2 billion people, is traditionally diagnosed through invasive and resource-intensive blood tests. These methods can be a hassle, expensive, and sometimes impossible to access, especially in low-resource settings. This review paper synthesizes key research on how Artificial Intelligence (AI) and Deep Learning (DL) are transforming diagnostics by developing non-invasive, accessible, and scalable alternatives. Instead of drawing blood, AI models are being trained to analyze subtle physiological changes. The research in this domain primarily focuses on leveraging visual and physiological data that can be captured easily, often with a smartphone.

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Introduction

Image-Based Analysis Using Convolutional Neural Networks (CNNs). The majority of studies use Convolutional Neural Networks (CNNs), a type of AI that is particularly good at analyzing images. Think of a CNN as a super-powered image processor that learns to recognize patterns in images, from simple lines to complex features like the paleness of skin. Several studies have focused on analyzing images of the palpebral conjunctiva (the inner lower eyelid), a classic clinical sign of anemia.

- A study by Appiahene et al. (2023) developed a CNN model that achieved 90.27% accuracy in detecting anemia from captured and processed images.
- Jain et al. (2019) used a least squares support vector machine (LS-SVM) to analyze conjunctiva images, achieving promising metrics of 85% precision, 92% sensitivity, and 70% specificity.
- Research published in Healthcare Informatics Research (2025) used an ensemble of VGG16, ResNet-50, and InceptionV3 models, achieving a high Area Under the Curve (AUC) score of 0.97 for anemia detection.
- Other works have explored using various CNN architectures like MobileNet and Xception to analyze lip mucosa images, with some models achieving over 99% accuracy in specific datasets, Jain, et al., 2019; Suthaharan et al., 2016.

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Another popular and robust approach involves analyzing nail bed images. Nail beds have minimal melanin, which reduces the impact of skin tone on color analysis.

- Mannino et al. (2018) developed a smartphone app that estimates hemoglobin levels by analyzing the color of fingernail photos, reporting a sensitivity of 97% for detecting anemia.
- A recent paper in Robert et al., 2025, evaluated a non-invasive AI-augmented smartphone app using over 1.4 million "fingernail selfies" and reported strong real-world performance with 89% sensitivity and 93% specificity.

Other Machine Learning and Data-Driven Approaches. While image-based methods dominate, some studies have explored other machine learning techniques and data sources.

- Research has shown that AI can effectively analyze existing blood count data to classify different types of anemia (e.g., microcytic, normocytic, macrocytic) with very high accuracy, sometimes approaching 99% using models like Random Forest Jorge et al., 2023.
- Other studies have explored using physiological data from wearables and photoplethysmography (PPG) signals to predict hemoglobin levels, validating the potential of multi-modal data for diagnosis, Khan et al., 2019.

Results and Discussion

Key Findings and Performance Metrics The literature consistently

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demonstrates the high potential of AI and DL for anemia prediction. Most studies report high accuracy for binary classification, often exceeding 90% in controlled research settings.

- Sensitivity and specificity are crucial for diagnostic tools. Some non-invasive models show sensitivity over 90%, which is vital for not missing cases of anemia.
- To make predictions more reliable, researchers use Ensemble Methods, which combine the results from several models.
- Many studies utilize transfer learning, a clever trick that takes a pre-trained CNN model (e.g., ResNet-50) and fine-tunes it on a smaller dataset of anemia images. This makes models smarter and faster by leveraging existing knowledge, Jorge et al., 2023, Roy et al., 2023.
- An interesting finding by one study on conjunctival images was that the lower half area of the conjunctiva was a crucial region for hemoglobin value prediction Mannino et al., 2018. The Good, the Bad, and the Challenges. While the results are promising, there are several significant challenges that must be addressed before this technology becomes a regular part of a checkup.

- The Data Problem: AI models are only as smart as the data they're trained on. A major limitation is the lack of large, multi-ethnic, and well-labeled datasets, which can lead to models that don't generalize

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well across different populations or skin tones Ghosh, et al., 2022, Yilmaz, el al., 2022. This can result in algorithmic bias.

- The "Lighting" Problem: The performance of image-based models is highly sensitive to external factors like lighting conditions and device-specific variations in camera quality Ghosal et al., 2022. Robust solutions require sophisticated image normalization to operate reliably in any situation.
- The "Trust" Problem: These tools require rigorous clinical trials, just like any new medical device. The transition from a research prototype to a certified medical device is a long and serious process, Robert et al., 2025.
- The "Explaining Itself" Problem: To build trust with doctors, AI models need to be more transparent. Explainable AI (XAI) is a field dedicated to making AI show its work and explain *why* it made a specific prediction, helping clinicians to feel more confident, Appiahene et al., 2023.

Future Scope

The future looks promising as researchers work to overcome these challenges.

- The "Holistic" Approach: Integrating data from multiple sources (e.g., eye image, skin tone, and physiological data from wearables) could create more robust and accurate predictive models, Shen et al. 2021.

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- Instant Results: Developing lightweight DL models that can run directly on a smartphone or other edge devices would enable real-time, on-site screening without needing an internet connection Bahadure et al.,2024.
- Solving the Data Scarcity: Scientists are even exploring ways to create realistic, synthetic images using technology like Generative Adversarial Networks (GANs) to train these models, helping them get smarter even without a massive amount of real-world data, Tamir, et al., 2017, Nithya et al., 2023.

Conclusion

The application of AI and DL for non-invasive anemia prediction is a significant step toward making healthcare more accessible and proactive. By transforming a smartphone camera into a potential screening tool, this technology offers a scalable and accessible solution for a condition that affects billions. The collective body of research provides strong evidence for the feasibility and accuracy of these methods. As the field matures, AI-powered diagnostic tools are poised to revolutionize anemia screening and contribute to global health initiatives, enabling earlier detection and intervention for those who need it most.

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