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OCULOMICS: AN ARTIFICIAL INTELLIGENCE–DRIVEN FRAMEWORK FOR RETINAL IMAGING IN SYSTEMIC DISEASE ASSESSMENT

***[1]Dr. Mahesh Chandra, [2]Dr. Jitendra Singh, [3]Dr. Gaurav Dubey, [4]Imran Ahmad Ansari, [5]Kunwar Abhinav Singh, [6]Vishnu Datt Tiwari, [7]Ayush Jha**

[1]Dr Sushila Tewari Hospital & Government Medical College, Haldwani, Uttarakhand, India.
https://orcid.org/0000-0002-3250-8672
[2]Clear Vision,(eye care centre), 1001, Sec-29, Faridabad, Haryana, India.
https://orcid.org/0009-0005-4040-0687
[3]Uttar Pradesh University of Medical Sciences, Saifai, Etawah, Uttar Pradesh.
https://orcid.org/0000-0002-5164-6034
[4]Surajmal Agarwal, College of Peramedical and health eye care, Kichha, US Nagar,Uttarakhand.
https://orcid.org/0009-0006-1531-9200
[5]Mahent Avaidhyanath Paramedical College, Mahayogi Gorakhnath University, Gorakhpur.
https://orcid.org/0009-0005-6554-1793
[6]Divya College Of Health Sciences, Maharajganj, UP.
https://orcid.org/0009-0005-2360-3570
[7]Jeewan Daan Medical Centre, Multi-specialty Hospital, Motinagar, Haldwani Uttarakhand.
https://orcid.org/0009-0002-9862-0912

***Corresponding Author: Dr. Mahesh Chandra**
Dr Sushila Tewari Hospital & Government Medical College, Haldwani, Uttarakhand, India.
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ABSTRACT

The retina offers a unique, non-invasive window into systemic health owing to its shared embryological origin with the central nervous system and its capacity for direct visualisation of microvascular and neural structures. Recent advances in retinal imaging modalities, including colour fundus photography, optical coherence tomography, optical coherence tomography angiography, fundus autofluorescence, and emerging molecular techniques, have expanded the utility of ocular biomarkers beyond traditional ophthalmic disease assessment. The convergence of these technologies with artificial intelligence has led to the emergence of oculomics, a field focused on extracting systemic health information from retinal data. Artificial intelligence-enabled analysis supports automated, scalable, and reproducible extraction of complex retinal features and facilitates multimodal data integration, enhancing detection of subtle structural, vascular, and metabolic alterations. Retinal biomarkers derived through oculomics have shown associations with a wide range of systemic conditions, including cardiovascular disease, diabetes mellitus, neurodegenerative disorders, renal disease, and inflammatory and autoimmune conditions, underscoring the potential of the retina as a surrogate marker of systemic pathology. Despite its promise, challenges related to model interpretability, algorithmic bias, data privacy, and external validation must be addressed to enable responsible clinical translation. This review summarises current advances in retinal imaging based oculomics, highlighting the role of artificial intelligence–driven multimodal integration in systemic disease assessment and its potential contribution to precision medicine and preventive healthcare.

KEYWORDS: Oculomics; Retinal imaging; Fundus photography; Optical coherence tomography; Artificial intelligence; Systemic disease screening; Optometry.

INTRODUCTION

The retina occupies a unique position as a window to systemic health, as it permits direct, non-invasive visualisation of the body's microcirculation and neural tissue. As an embryological extension of the central nervous system, the retina shares close structural, physiological, and pathological relationships with both the brain and the systemic vasculature.[1,2] Consequently, retinal microvascular alterations have long been linked to a range of systemic disorders, including hypertension, diabetes mellitus, stroke, and cardiovascular disease.[3]

Recent advances in retinal imaging technologies and computational analytics have transformed retinal images into rich sources of systemic biomarkers. The integration of high-resolution retinal imaging with artificial intelligence has given rise to oculomics, an emerging discipline focused on deriving systemic health insights from ocular data.[4] This paradigm shift carries significant implications for optometric practice, positioning optometrists at the forefront of preventive, predictive, and integrative healthcare.

Contemporary fundus imaging has evolved considerably, with improvements in image quality, portability, and affordability. Smartphone-based fundus imaging systems have expanded access to retinal screening, particularly in resource-limited settings; however, challenges related to image quality, consistency, and user dependency remain.[5–7] Currently, retinal imaging is routinely performed using mydriatic cameras for detailed fundus evaluation, non-mydriatic cameras for rapid, high-resolution imaging without pharmacological dilation, and handheld devices for flexible use across diverse clinical environments.[8,9] In addition, ultra-widefield imaging has enhanced visualisation of the peripheral retina for comprehensive disease assessment. Advances in ocular angiography, pediatric retinal imaging, and optical coherence tomography (OCT), coupled with AI-assisted image processing and data interpretation, have further strengthened the role of retinal imaging as a powerful tool for systemic disease detection and oculomics-driven research.[8]

CONCEPT AND EVOLUTION OF OCULOMICS

Oculomics involves the high-throughput, quantitative evaluation of ocular imaging datasets to derive biomarkers indicative of systemic disease. Initial oculometric investigations predominantly employed manual measurements of retinal vascular parameters, such as vessel calibre, arteriovenous ratio, and vascular tortuosity, which were shown to have predictive value for cardiovascular and cerebrovascular outcomes.[3]

The advent of deep learning techniques represented a major methodological advancement in this field. Later investigations showed that convolutional neural networks trained on fundus images were capable of estimating demographic attributes and key systemic risk factors such, as age, sex, blood pressure, smoking habits, and overall cardiovascular risk with performance levels that were clinically meaningful.

These findings confirmed that retinal images contain latent systemic information not readily appreciated by human observers.[10,11]

More recently, oculomics has expanded to include multimodal imaging such as OCT and OCT angiography (OCTA), enabling combined assessment of neural and vascular biomarkers. This evolution has broadened the scope of oculomics from vascular epidemiology to neurodegeneration, metabolic disease, and renal pathology.[12]

Advances in retinal imaging technologies have operationalised the concept of oculomics by enabling quantitative assessment of structural, vascular, metabolic, and cellular biomarkers.

1. COLOR FUNDUS PHOTOGRAPHY (CFP):

Colour fundus photography (CFP) remains the most widely used and globally accessible retinal imaging modality, forming the foundation of retinal phenotyping in oculomics. CFP enables non-invasive visualisation of the optic disc, retinal vasculature, macula, and posterior pole, providing essential structural and vascular information relevant to both ocular and systemic health. Owing to its low cost, ease of acquisition, and scalability, CFP has been extensively employed in epidemiological studies and large population-based screening programs.[2,3]

Retinal characteristics identified on colour fundus photography, such as alterations in arteriolar and venular calibre, increased vascular tortuosity, microaneurysms, retinal haemorrhages, and optic disc abnormalities, have been consistently linked to systemic disorders including hypertension, diabetes mellitus, cerebrovascular disease, and cardiovascular pathology. These microvascular retinal changes mirror widespread endothelial dysfunction and common vascular mechanisms, reinforcing the role of the retina as an accessible indicator of systemic vascular status. Large cohort studies have demonstrated that quantitative and qualitative CFP-derived metrics can predict cerebrovascular events, cardiovascular morbidity, and mortality.[2,3,13,14]

Recent advances in artificial intelligence and deep learning have substantially expanded the role of CFP within oculomics. Deep learning algorithms applied to colour fundus photographs have demonstrated the capacity to infer cardiovascular risk indicators, such as demographic characteristics, smoking behaviour, blood pressure levels, and the likelihood of major adverse cardiovascular events, without reliance on predefined or manually extracted imaging features.[10,11] Furthermore, AI-enabled CFP analysis has been validated across multiethnic populations for the detection of diabetic

retinopathy and related retinal diseases, reinforcing its robustness and generalizability in real-world clinical settings.[15]

The emergence of smartphone-based fundus photography has further enhanced the reach of CFP by addressing barriers related to portability, cost, and access to care. Smartphone-assisted retinal imaging systems have demonstrated acceptable agreement with conventional fundus cameras and have been successfully implemented in large-scale diabetic retinopathy screening programs, particularly in resource-limited settings.[5,6,7] Systematic reviews and meta-analyses support the diagnostic reliability of smartphone-based CFP, although challenges related to image quality, field of view, and operator dependence remain.[8,9]

Within the oculomics framework, CFP serves as a population-level, scalable imaging platform that bridges traditional retinal examination with data-driven systemic risk prediction. Its compatibility with artificial intelligence, combined with widespread availability, positions CFP as a critical entry point for integrating retinal imaging into preventive, predictive, and personalised healthcare models.

2. STRUCTURAL RETINAL IMAGING - OPTICAL COHERENCE TOMOGRAPHY

It has revolutionised retinal imaging by enabling high-resolution, cross-sectional visualisation of retinal microarchitecture in a rapid, non-invasive manner. By employing low-coherence interferometry, OCT provides micrometre-scale resolution of individual retinal layers, allowing precise assessment of both neuronal and axonal integrity. Owing to its reproducibility and quantitative capability, OCT has become an indispensable tool in both clinical practice and research.

Considering the shared embryonic origin and close anatomical relationship between the retina and the central nervous system, OCT-derived structural parameters have emerged as surrogate markers of neurodegeneration and neuroaxonal loss. Thinning of the retinal nerve fibre layer (RNFL) and ganglion cell–inner plexiform layer (GC-IPL) has been consistently reported in neurological disorders, including multiple sclerosis, Alzheimer's disease, and other dementias, reflecting parallel degenerative processes occurring within the brain.[11–14] Longitudinal OCT studies have further demonstrated correlations between progressive retinal thinning and cerebral atrophy, underscoring the potential of OCT as a non-invasive biomarker for monitoring neurodegenerative disease progression.[16-18]

Beyond neurodegeneration, OCT has also shown relevance in systemic vascular and metabolic disorders. Subtle alterations in retinal layer thickness and macular architecture have been observed in patients with diabetes mellitus and cardiovascular disease, even in the absence of overt retinopathy. These findings suggest that structural retinal changes may precede clinically detectable microvascular damage, thereby offering opportunities for early risk stratification and intervention.[16]

Recent advances in image processing and artificial intelligence have further enhanced the analytical power of OCT. Automated segmentation algorithms now allow reliable, large-scale quantification of retinal layers, facilitating population-based studies and integration into predictive models. When combined with machine learning approaches, OCT data can contribute to individualised disease profiling and longitudinal monitoring, aligning structural retinal imaging with the broader framework of oculomics.

3. OPTICAL COHERENCE TOMOGRAPHY ANGIOGRAPHY (OCTA)[19-21]

Optical coherence tomography angiography (OCTA) represents a major advancement in retinal vascular imaging by enabling non-invasive, depth-resolved visualisation of the retinal and choroidal microvasculature without the use of exogenous contrast agents. OCTA generates angiographic information by detecting motion contrast arising from erythrocytes flowing within blood vessels, allowing high-resolution mapping of the superficial, deep, and choriocapillaris vascular plexuses.

Quantitative OCTA-derived biomarkers, such as vessel density, perfusion density, capillary non-perfusion areas, and foveal avascular zone (FAZ) metrics, have demonstrated robust associations with systemic diseases, including diabetes mellitus, cardiovascular disease, chronic kidney disease, and systemic autoimmune disorders. These vascular alterations reflect endothelial dysfunction, impaired autoregulation, and capillary dropout, which are hallmark features of systemic microangiopathy.

In diabetes mellitus, OCTA has revealed reductions in vessel density and FAZ enlargement before the clinical manifestation of diabetic retinopathy, highlighting its potential role in early disease detection and risk stratification. Similarly, altered retinal perfusion patterns and reduced vascular complexity observed on OCTA have been linked to cardiovascular disease, supporting the concept that retinal microvascular health mirrors systemic vascular integrity. In chronic kidney disease, OCTA parameters correlate with declining renal function, reinforcing the presence of shared microvascular pathology between the retina and kidneys.

By enabling capillary-level assessment of vascular integrity, OCTA provides a unique window into early systemic microvascular dysfunction. These attributes position OCTA as a cornerstone imaging modality within oculomics, supporting its integration into non-invasive screening, monitoring, and prognostic models for systemic disease.

4. FUNDUS AUTO-FLUORESCENCE (FAF)

Fundus autofluorescence (FAF) is a non-invasive imaging modality that captures signals arising from endogenous retinal fluorophores, with lipofuscin accumulation in the retinal pigment epithelium serving as the dominant source. This technique has become an important tool for the detection and longitudinal assessment of retinal conditions, including retinitis pigmentosa, age-related macular degeneration, macular dystrophies, and various white dot syndromes.[22]

FAF images are generated using specific excitation and emission wavelengths, with modern devices employing one or more optical filters to enhance image quality. However, intrinsic fluorophores with overlapping excitation or emission spectra may confound FAF signals, potentially affecting image interpretation and clarity.[21] Despite these technical limitations, FAF remains a powerful modality for assessing retinal metabolic stress and photoreceptor–RPE integrity.

Beyond ocular disease, autofluorescence has shown significant potential as a systemic diagnostic biomarker. Wang et al. demonstrated that machine-learning analysis of autofluorescence intensity patterns could classify T-cell functional activity in human blood samples, highlighting the broader applicability of autofluorescence in immune profiling.[23,24] In a related application, hyperspectral autofluorescence imaging combined with deep learning successfully distinguished inflammatory pain states by identifying immune cell–specific metabolic signatures.[25]

Lipofuscin is composed of multiple fluorophores generated through oxidative stress–related reactions. Its accumulation has been observed not only in the retina but also in the brain during ageing, injury, and neurodegenerative disease, suggesting that autofluorescence may serve as a shared metabolic marker of tissue damage across neural systems.[26,27] These observations strengthen the role of FAF within oculomics as a modality capable of reflecting both retinal and systemic metabolic dysfunction.

5. RAMAN SPECTROSCOPY

Raman spectroscopy is an emerging optical diagnostic technique that provides molecular-level information based on vibrational frequencies of chemical bonds within tissues. By detecting disease-specific biochemical signatures, Raman spectroscopy offers a label-free approach for identifying pathological changes at an early stage.[27]

Recent advances have enabled the integration of Raman spectroscopy with ophthalmic imaging platforms. Alba-Arbalat et al. combined Raman spectroscopy with a controlled-wavelength laser ophthalmoscope to assess retinal molecular alterations in patients with multiple sclerosis, demonstrating in vivo detection of neuroinflammatory and neurodegenerative changes.[28] This prototype represents a promising step toward non-invasive molecular phenotyping of retinal tissue.

Although still largely investigational, Raman spectroscopy holds substantial promise for oculomics by enabling direct assessment of biochemical and metabolic changes that precede structural or vascular abnormalities. As technological refinement continues, Raman-based retinal imaging may complement OCT, OCTA, and FAF by adding a molecular dimension to systemic disease detection through the eye.[28]

Table 1: Comparison of OCTA and FAF in Oculomics and Systemic Disease Assessment.

FEATURE	OCT ANGIOGRAPHY (OCTA)	FUNDUS AUTOFLUORESCENCE (FAF)
Primary target	Retinal and choroidal microvasculature	Metabolic fluorophores (lipofuscin)
Key biomarkers	Vessel density, perfusion density, and FAZ metrics	Auto-fluorescence intensity & patterns
Spatial resolution	Capillary-level vascular detail	RPE-level metabolic mapping
Systemic relevance	Diabetes, cardiovascular disease, and chronic kidney disease	Immune activity, inflammation, and neurodegeneration
Role in oculomics	Micro-angiopathy assessment	Metabolic and oxidative stress biomarkers
Clinical application	Early vascular dysfunction detection	Disease monitoring and systemic biomarker research

ARTIFICIAL INTELLIGENCE IN OCULOMICS: METHODOLOGICAL AND MULTIMODAL PERSPECTIVES

Artificial intelligence (AI) forms the analytical foundation of oculomics by enabling automated extraction of complex and high-dimensional features from large retinal imaging datasets. Machine learning and deep learning approaches support objective, scalable, and reproducible analysis of ocular images, making them particularly suitable for population-level screening and systemic disease prediction.[14,16]

A defining strength of oculomics lies in the integration of information obtained from multiple retinal imaging modalities, including colour fundus photography, optical coherence tomography, OCT angiography, fundus autofluorescence, and emerging molecular and spectroscopic techniques. AI provides a unified computational framework for multimodal data fusion, allowing complementary structural, vascular, and metabolic retinal signals to be analysed simultaneously. Such multimodal integration has been shown to enhance predictive performance and improve systemic disease risk stratification compared with single-modality approaches.[26,30,31]

In ophthalmic practice, AI-based systems have demonstrated robust diagnostic and screening performance across a wide spectrum of ocular conditions, like diabetic retinopathy, diabetic macular oedema, age-related macular degeneration, glaucoma, cataract, and keratoconus, supporting their clinical feasibility and translational potential.[32,33] Building on these established applications, oculomics extends AI-driven retinal analysis beyond ocular pathology to infer systemic disease risk and multisystem health status using non-invasive retinal data.[14,26]

From a methodological perspective, deep learning represents a key subset of AI and has gained prominence due to its ability to learn hierarchical image features without explicit feature engineering. Convolutional neural networks and related architectures have been widely adopted in ophthalmology for automated image interpretation, risk prediction, and clinical decision support.[34,35] However, despite their high performance, these models often function as "black boxes," limiting interpretability and clinical trust.

Several challenges must therefore be addressed to enable responsible clinical deployment of AI-driven oculomics. These include the risk of algorithmic bias, limited generalisability across diverse populations, data privacy concerns, and the need for robust external validation and regulatory oversight.[37–39] Addressing these ethical and methodological considerations is essential to ensure safe, equitable, and transparent integration of oculomics-based tools into routine clinical practice.

Overall, artificial intelligence enables multimodal retinal data integration, high-throughput phenotyping, and systems-level interpretation of ocular biomarkers, positioning oculomics as a promising approach for non-invasive assessment of systemic disease. With continued methodological refinement and appropriate governance frameworks, AI-powered oculomics is expected to play an increasingly important role in precision medicine and preventive healthcare.

RETINAL BIOMARKERS AND SYSTEMIC DISEASES

Retinal imaging provides a unique opportunity to identify quantifiable biomarkers that reflect systemic pathological processes. Because the retina shares embryological, microvascular, and neurodegenerative pathways with multiple organ systems, retinal biomarkers offer a non-invasive means of assessing systemic disease burden, progression, and risk. In oculomics, these biomarkers are derived from structural, vascular, metabolic, and cellular alterations captured across multimodal retinal imaging platforms.

1. **CARDIOVASCULAR DISEASE-** Retinal vascular biomarkers have long been recognised as indicators of cardiovascular and cerebrovascular health. Features such as arteriolar narrowing, venular dilatation, arteriovenous nicking, and increased vessel tortuosity, identified on colour fundus photography, are associated with hypertension, atherosclerosis, stroke, and cardiovascular mortality. These changes reflect systemic endothelial dysfunction and altered hemodynamics.[2,3,13,14]

Advances in OCTA have enabled capillary-level assessment of retinal microcirculation, revealing reduced vessel density, perfusion deficits, and foveal avascular zone enlargement in individuals with cardiovascular disease, even in the absence of overt ocular pathology.[18] AI-driven analysis of fundus photographs has further shown the capacity to infer cardiovascular risk factors and major adverse cardiovascular events, highlighting the retina's potential role in population-level cardiovascular risk stratification.[10,11,31]

2. **DIABETES MELLITUS-** Diabetes mellitus is characterised by progressive microvascular and neurodegenerative changes, many of which are detectable in the retina before clinical disease manifestation. Structural OCT has revealed early retinal nerve fibre layer (RNFL) and ganglion cell–inner plexiform layer (GCIPL) thinning**,** supporting the concept of diabetic retinal neurodegeneration as an early event in disease pathophysiology.[16]

OCTA-derived biomarkers, including reduced capillary density and increased non-perfusion areas, have been observed before the development of clinically detectable diabetic retinopathy, underscoring their utility in early detection and risk assessment.**[15,27]** Fundus autofluorescence further contributes to metabolic insight by revealing retinal pigment epithelium stress and oxidative damage, which are closely linked to chronic hyperglycemia and metabolic dysregulation.[22] Together, these retinal biomarkers provide a multidimensional view of diabetic microangiopathy and neurodegeneration.

3. **NEURODEGENERATIVE DISORDERS-** The retina's embryological origin as an extension of the central nervous system positions it as a valuable surrogate for neurodegenerative disease assessment. OCT studies have consistently demonstrated thinning of the RNFL and GCIPL in conditions such as Alzheimer's disease and multiple sclerosis, correlating with cognitive decline, cerebral atrophy, and disease severity.[16–18]

Metabolic and inflammatory biomarkers detected through autofluorescence imaging further enhance this association. Retinal microglia—central nervous system immune cells—exhibit strong autofluorescence signatures related to changes in morphology, gene expression, and metabolic activity during neuroinflammatory and neurodegenerative states.**[26,34]** These microglial alterations appear as hyperreflective foci (HRF) on OCT and FAF imaging and have been identified in multiple sclerosis and other

neuroinflammatory conditions. Such findings suggest that retinal microglial activity may serve as an accessible biomarker of brain inflammation and neurodegeneration.[11,35,36]

4. **RENAL AND AUTOIMMUNE DISORDERS-** Systemic diseases characterised by microvascular injury, such as chronic kidney disease and autoimmune disorders, also demonstrate retinal biomarker signatures. OCTA studies have shown correlations between reduced retinal microvascular density and declining renal function, supporting the concept of a shared retinal–renal microvascular axis.[16] In autoimmune conditions such as systemic lupus erythematosus, OCTA-derived vascular alterations persist even during clinically inactive disease states, suggesting subclinical microvascular involvement.[20,21]

Retinal biomarkers have also been explored in rare systemic conditions, including von Hippel–Lindau disease, where HRF and microvascular changes reflect underlying systemic pathology.[26] These observations reinforce the role of the retina as a sensitive indicator of systemic immune-mediated and microvascular dysfunction.

Table 2: Retinal Imaging Modalities and Associated Systemic Biomarkers.

Imaging Modality	Key Retinal Biomarkers	Systemic Diseases Implicated
CFP	Vessel calibre, tortuosity	CVD, Stroke, Hypertension
OCT	RNFL, GCIPL thinning	Alzheimer's, MS, Diabetes
OCTA	Vessel density, FAZ	CVD, CKD, Diabetes
FAF	Lipofuscin patterns, HRF	Neurodegeneration, Metabolic disease
Raman	Molecular signatures	Neuroinflammation, MS

CLINICAL IMPLICATIONS FOR OPTOMETRIC PRACTICE

The integration of oculomics into routine optometric examinations positions optometrists as frontline providers in systemic disease screening. Opportunistic retinal imaging during comprehensive eye examinations offers a unique opportunity for early detection of systemic disease in asymptomatic individuals.[4,33]

By facilitating timely referral and interdisciplinary collaboration, optometrists can play a pivotal role in preventive healthcare and public health strategies.

ETHICAL, LEGAL, AND PRACTICAL CONSIDERATIONS

The application of oculomics raises ethical concerns related to data privacy, informed consent, and medico-legal responsibility. Clear guidelines regarding data usage, algorithm transparency, and clinical accountability are essential.[32,40]

Standardisation of imaging protocols and regulatory oversight will be critical for widespread adoption.

FUTURE DIRECTIONS

The translation of oculomics from research to routine clinical practice will depend on the standardisation and longitudinal validation of retinal biomarkers across diverse populations and imaging platforms. Future efforts should focus on integrating multimodal retinal data with systemic clinical information to enable comprehensive, multisystem risk assessment rather than single-disease prediction. Advances in artificial intelligence are expected to enhance the interpretability and clinical usability of oculomic outputs, allowing retinal imaging findings to be translated into actionable risk scores and referral pathways within routine eye care. Optometrists are uniquely positioned to contribute to preventive healthcare through early identification of systemic disease risk during regular eye examinations. Concurrently, ethical challenges such as the protection of patient data, mitigation of algorithmic bias, and assurance of equitable access require careful consideration to support responsible clinical adoption. In parallel, advances in molecular imaging hold promise for enhancing the biological resolution of oculomics by facilitating the identification of biochemical changes that occur before detectable structural or vascular abnormalities, thereby strengthening the role of retinal assessment as an early and accessible marker of systemic disease.[4,40]

DISCUSSION

The expanding field of oculomics reflects a paradigm shift in vision science, positioning the retina as a valuable source of systemic biomarkers rather than an isolated end organ. Owing to its shared embryological origin with the central nervous system and its dense microvascular and neural architecture, the retina offers a unique opportunity for non-invasive assessment of systemic vascular, metabolic, and neurodegenerative processes. Advances in retinal imaging technologies have substantially enhanced the resolution, depth, and functional information obtainable from ocular tissues, thereby enabling more comprehensive characterisation of systemic disease signatures.

This review highlights how multimodal retinal imaging—including colour fundus photography, optical coherence tomography, OCT angiography, fundus autofluorescence, and emerging molecular and spectroscopic techniques—captures complementary structural, vascular, and metabolic information. Individually, these modalities provide valuable insights into disease-specific changes; however, their true potential is realised when integrated through artificial

intelligence–driven analytical frameworks. Multimodal oculomics enables holistic retinal phenotyping, improving sensitivity to early and subtle disease-related alterations that may precede overt clinical manifestations in systemic disorders.

Artificial intelligence plays a central role in translating complex retinal data into clinically meaningful insights. Deep learning approaches facilitate automated feature extraction and pattern recognition without reliance on predefined imaging markers, supporting scalable population-level screening and risk stratification. Importantly, AI-driven oculomics extends retinal image analysis beyond traditional ophthalmic diagnoses to infer systemic health status, reinforcing the concept of the eye as an accessible proxy for multisystem disease assessment. These capabilities have particular relevance for cardiovascular disease, diabetes mellitus, neurodegenerative disorders, renal disease, and inflammatory conditions, where early microvascular or neural changes may be reflected in the retina.

Despite these advances, several challenges must be addressed before widespread clinical adoption of oculomics can be achieved. Limited interpretability of deep learning models continues to hinder clinician trust and regulatory acceptance, while algorithmic bias arising from non-representative training datasets may compromise generalisability across diverse populations. Data privacy, ethical governance, and standardisation of imaging protocols also remain critical considerations. Addressing these challenges will require interdisciplinary collaboration, robust external validation, and the development of transparent and accountable AI frameworks.

Looking forward, integration of retinal imaging–based oculomics into routine clinical workflows holds significant promise for precision medicine and preventive healthcare. As imaging technologies evolve and analytical methods mature, oculomics may facilitate earlier disease detection, improved risk stratification, and longitudinal monitoring of systemic conditions through a simple, non-invasive ocular examination. Continued research focusing on clinical validation, ethical implementation, and translational pathways will be essential to realise the full potential of oculomics in systemic disease management.

CONCLUSION

Oculomics represents a paradigm shift in eye care by positioning the retina as a non-invasive gateway to systemic health assessment. Advances in retinal imaging modalities, including colour fundus photography, OCT, OCT angiography, fundus autofluorescence, and emerging molecular techniques, have enabled the identification of retinal biomarkers reflecting vascular, neurodegenerative, metabolic, and inflammatory pathways. When combined with artificial intelligence–driven analytics, these biomarkers enable scalable and reproducible approaches for early disease identification, risk assessment, and longitudinal monitoring of systemic conditions, including cardiovascular disease, diabetes mellitus, neurodegenerative disorders, renal dysfunction, and autoimmune diseases. As evidence continues to evolve, oculomics has the potential to extend the role of optometry and ophthalmology beyond ocular disease management toward preventive and integrative healthcare. Continued validation, standardisation, and ethical deployment will be essential to translate this promising approach into routine clinical practice.

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