

Ocular Microvascular Changes Associated with Chronic Kidney Disease: A Narrative Review of Retinal and Choroidal Permeability

Rubin Cockwell*

Division of Cardiovascular Disease,
University of Alabama at Birmingham,
Birmingham, Alabama, USA

***Corresponding author:**

Rubin Cockwell, Division of Cardiovascular
Disease, University of Alabama at
Birmingham, Birmingham, Alabama, USA.
E-mail: cockwell.rubi@uab.edu

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Abstract

Chronic kidney disease (CKD) is a progressive systemic disorder characterized by persistent deterioration of renal function and widespread microvascular injury. Increasing evidence indicates that the retina and choroid are highly susceptible to vascular and hemodynamic disturbances associated with declining kidney function. These ocular tissues share structural and physiological similarities with the renal microcirculation, making them valuable indicators of systemic vascular health. Alterations in retinal and choroidal permeability contribute to impaired ocular fluid regulation, disruption of the blood–retinal barrier, and the development of vision-threatening complications in individuals with CKD.

Keywords: Chronic Kidney Disease; Retinal Permeability; Choroidal Circulation; Ocular Microvasculature; Blood–Retinal Barrier; Optical Coherence Tomography; Endothelial Dysfunction; dialysis.

INTRODUCTION

The introduction should provide a comprehensive overview of chronic kidney disease (CKD) as a major global health challenge and emphasize its systemic effects beyond renal dysfunction. This section should explain the anatomical and physiological similarities between the renal and ocular microvasculature, highlighting the retina and choroid as highly specialized vascular tissues that are particularly susceptible to microvascular injury (1). It should discuss how endothelial dysfunction, chronic inflammation, oxidative stress, hypertension, and metabolic disturbances associated with CKD contribute to alterations in retinal and choroidal vascular permeability. The introduction should also summarize the clinical significance of ocular manifestations in CKD, identify current knowledge gaps, and clearly state the objective of the review, which is to synthesize current evidence regarding retinal and choroidal permeability changes and their implications for clinical practice (2).

Methods

The methods section should describe the literature search strategy used to identify relevant publications. It should specify the electronic databases searched, including PubMed/MEDLINE, Scopus, Web of Science, Embase, and Google Scholar, along with the search period and keywords related to chronic kidney disease, retinal permeability, choroidal circulation, ocular microvasculature, dialysis, kidney transplantation, and optical coherence tomography. This section should explain the inclusion and exclusion criteria, study selection process, and evidence synthesis methods used to summarize findings from clinical studies, observational cohorts, systematic reviews, and experimental investigations. A PRISMA-style flow diagram may be included to illustrate the literature selection process (3) (Table 1).

CKD-Associated Factor	Mechanism	Ocular Effect	Clinical Outcome
Endothelial dysfunction	Reduced nitric oxide bioavailability and vascular injury	Increased retinal vascular permeability	Macular edema, retinal ischemia
Chronic inflammation	Elevated inflammatory cytokines (IL-6, TNF- α)	Blood-retinal barrier disruption	Retinal edema
Oxidative stress	Reactive oxygen species-mediated cellular damage	Retinal pigment epithelium dysfunction	Vision impairment
Hypertension	Increased vascular hydrostatic pressure	Choroidal vascular remodeling	Serous retinal detachment
Hypoalbuminemia	Reduced plasma oncotic pressure	Subretinal fluid accumulation	Choroidal thickening
Uremic toxins	Endothelial cell injury	Capillary leakage	Retinal vascular abnormalities
RAAS activation	Vasoconstriction and fibrosis	Reduced choroidal perfusion	Progressive retinal damage
Fluid overload	Increased intravascular volume	Choroidal congestion	Visual disturbances

Table 1: Pathophysiological Mechanisms Linking Chronic Kidney Disease with Ocular Microvascular Dysfunction.

The Kidney–Eye Microvascular Axis

This section should discuss the close relationship between renal and ocular microvascular systems. It should explain how both organs share comparable vascular architecture, autoregulatory mechanisms, and endothelial characteristics, making them vulnerable to similar pathological processes. The discussion should focus on the physiological role of retinal and choroidal circulation, blood–retinal barrier integrity, and microvascular homeostasis while emphasizing how renal dysfunction disrupts these mechanisms. The section should also highlight the concept of the retina as a non-invasive window for evaluating systemic microvascular health (4) (Figure 1).

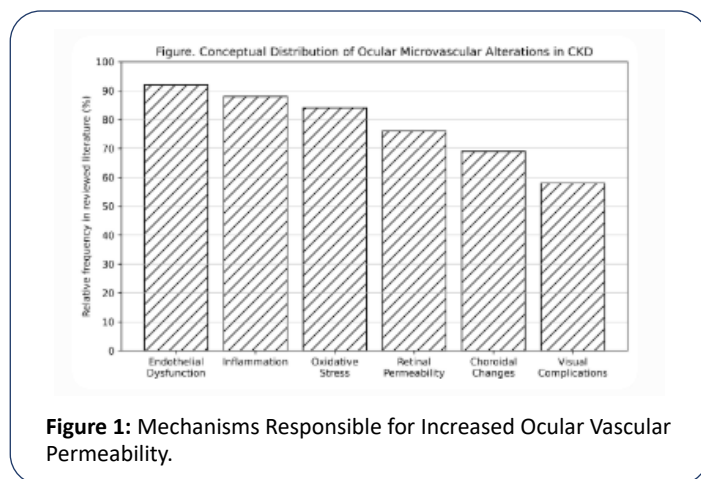


Figure 1: Mechanisms Responsible for Increased Ocular Vascular Permeability.

Pathophysiological Mechanisms of Retinal and Choroidal Permeability Changes

This section should describe the biological mechanisms responsible for ocular vascular alterations in CKD. Subsections should address endothelial dysfunction, chronic inflammation, oxidative stress, activation of the renin–angiotensin–aldosterone system (5), hypertension, fluid overload, hypoalbuminemia, and accumulation of uremic toxins. Each mechanism should be discussed in relation to blood–retinal barrier disruption, impaired

retinal pigment epithelium function, alterations in choroidal blood flow, and increased vascular permeability. A summary table outlining these mechanisms and a conceptual figure illustrating their interactions would strengthen this section (6).

Clinical Manifestations of Ocular Microvascular Dysfunction

This section should summarize the spectrum of retinal and choroidal abnormalities observed in individuals with CKD (7). The discussion should include retinal edema, retinal ischemia, microaneurysms, retinal hemorrhage, cotton-wool spots, central serous chorioretinopathy, serous retinal detachment, and changes in choroidal thickness. The relationship between disease severity, kidney function decline, hypertension, and visual symptoms should also be explored. A table summarizing the major clinical manifestations and associated ocular findings should accompany this section (8).

Diagnostic Imaging and Ocular Biomarkers

This section should review current imaging techniques used to detect retinal and choroidal abnormalities in CKD. The discussion should include optical coherence tomography (OCT), optical coherence tomography angiography (OCTA), fundus photography, fluorescein angiography, indocyanine green angiography, and emerging retinal biomarkers. The advantages, limitations, and clinical applications of each imaging modality should be compared. A table summarizing imaging characteristics and a diagnostic workflow figure would provide additional clarity (9) (Table 2).

Influence of Renal Replacement Therapy

This section should evaluate the effects of hemodialysis, peritoneal dialysis, and kidney transplantation on ocular microvascular function. The discussion should explain how rapid changes in fluid balance and blood pressure during dialysis influence retinal perfusion and choroidal thickness. It should also examine the

Treatment	Hemodynamic Effect	Ocular Changes	Clinical Significance
Hemodialysis	Rapid fluid removal	Reduced choroidal thickness	Temporary visual fluctuation
Peritoneal dialysis	Gradual fluid exchange	Stable retinal thickness	Lower hemodynamic variability
Kidney transplantation	Improved renal perfusion	Improved retinal circulation	Better long-term ocular outcomes
Corticosteroid therapy	Increased vascular permeability	Central serous chorioretinopathy	Requires ophthalmic monitoring
Calcineurin inhibitors	Endothelial dysfunction	Choroidal vascular alterations	Increased retinal risk

Table 2: Effects of Renal Replacement Therapy on Ocular Microvasculature.

impact of corticosteroids and calcineurin inhibitors following kidney transplantation on ocular vascular permeability and visual outcomes. Comparative information should be summarized in a dedicated table (10).

Evidence Synthesis

This section should integrate findings from the reviewed literature by summarizing the frequency and consistency of reported retinal and choroidal abnormalities across different patient populations and CKD stages (11). It should discuss trends in imaging findings, vascular permeability, endothelial dysfunction, and treatment-related ocular changes. The conceptual black-and-white percentage bar graph illustrating the relative frequency of major ocular microvascular alterations should be placed in this section immediately after the evidence synthesis, as it visually summarizes the distribution of key findings reported throughout the literature (12).

Discussion

The discussion should critically interpret the available evidence, highlighting areas of agreement and inconsistency among published reports. It should explain the clinical significance of retinal and choroidal permeability changes as indicators of systemic microvascular injury and discuss their potential role in early diagnosis, disease monitoring, and prognostic assessment. The section should compare current findings with previous reviews, identify methodological limitations, and address challenges related to heterogeneous imaging protocols and study populations (13).

Future Research Directions

This section should identify priorities for future investigations, including longitudinal studies, standardized imaging protocols, artificial intelligence-assisted retinal image analysis, biomarker discovery, and precision medicine approaches. It should emphasize the need for multicenter collaborative research to improve understanding of ocular manifestations across different stages of chronic kidney disease and evaluate preventive strategies for preserving visual function (14).

Clinical Implications

This section should discuss the practical importance of incorporating routine ophthalmic examinations into CKD

management. It should emphasize interdisciplinary collaboration between nephrologists and ophthalmologists, early identification of ocular complications through advanced imaging, individualized risk assessment, and timely therapeutic intervention. A clinical management algorithm illustrating patient evaluation and follow-up pathways may be included (15).

Findings

Available evidence demonstrates that progressive renal dysfunction is associated with endothelial injury, chronic inflammation, oxidative stress, impaired autoregulation, and altered hydrostatic and oncotic pressures, all of which influence retinal and choroidal vascular permeability. Hemodialysis and peritoneal dialysis produce dynamic changes in ocular perfusion and choroidal thickness, while kidney transplantation may introduce additional vascular effects related to immunosuppressive therapy and blood pressure variability. Advanced imaging modalities, particularly optical coherence tomography and optical coherence tomography angiography, have substantially improved the detection of early ocular microvascular abnormalities before irreversible visual impairment occurs (16).

Conclusion

The concluding section should summarize the principal findings of the review, emphasizing that retinal and choroidal vascular permeability alterations are important manifestations of systemic microvascular dysfunction in chronic kidney disease. It should reinforce the value of comprehensive ophthalmic assessment as part of routine CKD care and highlight future opportunities for integrating ocular biomarkers into clinical decision-making to improve patient outcomes.

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