BANTAO Journal 2026; 24(1): 42-48

BJ
BANTAO Journal

*Original article*

# Assessment of Retinal Microangiopathy in CKD and Dialysis Patients by Optical Coherence Tomography Angiography

Damir Rebic[1], Sanja Sefic[2], Aida Hamzic-Mehmedbasic[1], Aida Coric[1], Senad Hasanspahic[1] and Vedad Herenda[1]

[1]Clinic for Nephrology and Renal Replacement Therapy, Clinical Center University of Sarajevo, Sarajevo, [2]Eye Polyclinic "Dr. Sefic", Sarajevo, Bosnia and Herzegovina

**Abstract**

**Introduction.** Ocular microvascular changes may reflect the progression of kidney damage in chronic kidney disease (CKD). The aim of this study was to investigate the association between retinochoroidal parameters, assessed by optical coherence tomography angiography (OCTA), and the degree of kidney deterioration in CKD and dialysis patients.

**Methods.** In this cross-sectional study, the study group comprised patients with arterial hypertension at different stages of CKD and patients receiving dialysis treatment. A complete eye examination, including OCTA imaging of the macular region, was performed in all participants. According to the estimated glomerular filtration rate (eGFR), non-dialysed patients were divided into low-eGFR (<60 mL/min) and high-eGFR (>60 mL/min) groups, and CKD patients on renal replacement therapy were further classified according to the dialysis modality (hemodialysis or peritoneal dialysis).

**Results.** The analysis included 136 eyes of 100 CKD patients. Mean retinal thickness (Rt) was 275.73±9.65 µm in the low-eGFR group and 274.36±10.77 µm in the high-eGFR group; in dialysis patients, Rt increased from 273.4 µm before to 277.2 µm after the dialysis session. OCTA showed significantly lower deep vascular density (DVD) in CKD patients with albuminuria than in those without albuminuria ($p<0.001$). Albuminuria was inversely related to retinal and choroidal thickness and to superficial (SVD) and deep (DVD) vascular density.

**Conclusion.** In patients with CKD, decreasing kidney function is associated by a reduction of retinal and choroidal vascular density, as assessed by OCTA.

**Keywords:** microvasculature, chronic kidney disease, OCTA, chorioretinal thickness, vascular density

## Introduction

Chronic kidney disease (CKD) ranks among the most consequential public health problems of the modern era, with a steadily rising worldwide prevalence and a heavy contribution to overall morbidity and mortality. By current consensus, CKD is diagnosed when evidence of kidney damage persists for at least three months or when the estimated glomerular filtration rate (eGFR) remains below 60 mL/min/1.73 m². The Kidney Disease Outcomes Quality Initiative (KDOQI) classification stratifies the condition into five stages according to eGFR, the fifth of which, an eGFR below 15 mL/min/1.73 m², defines end-stage renal disease (ESRD) [1].

The disorder is remarkably prevalent. Community-based estimates suggest that 8-16% of adults are affected, with the figure rising steeply with age to approximately 30.8% among those aged 70 years or older [2]. CKD is also encountered in about 15% of non-diabetic hypertensive individuals and in 43-53% of patients with diabetes mellitus [3,4], and the overall burden is expected to double by 2035 as ageing populations and the diabetes epidemic continue to expand [5].

CKD is not confined to the kidneys. Its systemic reach extends to the cardiovascular, endocrine, gastrointestinal, and nervous systems, and the eye is a frequent target of the disease. Affected individuals carry an increased risk of cataract, glaucoma, age-related macular degeneration, retinopathy, and visual impairment [6-9], while coexisting diabetes mellitus and hypertension predispose specifically to diabetic and hypertensive retinopathy [10]. Beyond the eye, CKD is also linked to accelerated atherosclerosis, cerebrovascular disease, cognitive decline, and excess mortality [11-14]. Why ocular disease is so common in these patients remains debatable. Some authors emphasise the substantial overlap of risk factors-ageing, diabetes, hypertension, smoking, and obesity-between renal and ocular pathology. Others invoke mechanisms intrinsic to CKD itself, such as an oxidative stress triggered by the accumulation of nitrogenous waste products that generate free radicals, and inflammation sustained by activation of the renin-angiotensin system [15].

Once ESRD develops, renal replacement therapy (RRT) becomes necessary to preserve metabolic homeostasis,

the principal options being hemodialysis (HD), peritoneal dialysis (PD), and kidney transplantation [16]. PD may be administered either as continuous ambulatory peritoneal dialysis (CAPD) or as automated peritoneal dialysis (APD), according to the center's protocol. Dialysis inherently disturbs systemic hemodynamics and osmolality, engendering rapid fluctuations in blood pressure, plasma osmolarity, and fluid balance [17]. These swings are of particular ocular relevance because the retina and choroid are richly vascularized structures. Earlier work has suggested that dialysis may produce measurable changes in the thickness of the retina and choroid as well as in the retinal capillary perfusion, although the responsible mechanisms and their clinical significance remain poorly understood [18]. During hemodialysis in particular, ultrafiltration, osmotic shifts, and blood pressure variation can acutely influence ocular perfusion and tissue thickness, most notably in the choroid. In line with this, recent meta-analyses have documented a modest yet consistent reduction in subfoveal choroidal thickness after HD sessions, whereas retinal thickness parameters are largely stable in the acute setting [19], supporting the view that choroidal circulation responds particularly sensitively to the fluid and hemodynamic burden imposed by dialysis.

Superimposed on these acute phenomena, CKD drives longer-term structural remodelling of the eye. Chronic alterations include narrowing of the retinal arterioles, progressive choroidal thinning, and atrophy of the retinal nerve fiber layer (RNFL) and the ganglion cell–inner plexiform layer (GCIPL) [20,21]. Retinal vessel analysis has further revealed decreased retinal vessel diameter, reduced fractal dimension, focal narrowing of arterioles, arteriovenous nicking, and arteriolar wall opacification in CKD [19]. Such retinal microvascular features are increasingly regarded as surrogate markers of cardiovascular risk, cognitive impairment, and worsening renal function [22]. The concept that the eye mirrors systemic microvascular health is reinforced by the structural and autoregulatory resemblance between the retinal and renal microvasculatures and by demonstrated correlations between ocular structural parameters and renal injury markers, including reduced eGFR and increased albuminuria [22]. Data at the capillary level, however, remain sparse. Although scanning laser Doppler flowmetry has disclosed an increased intercapillary distance in CKD, the behavior of individual retinal vascular plexuses is largely unknown, and the contribution of systemic comorbidities to these microvascular changes has not been clarified [18].

Optical coherence tomography (OCT) and OCT angiography (OCTA) have transformed the assessment of retinal and choroidal morphology. OCT provides high-resolution measurements of retinal thickness, including central macular thickness, while OCTA delivers non-invasive, depth-resolved imaging of the retinal microvasculature with quantitative metrics of perfusion. Together, these modalities constitute a convenient and reproducible window onto microvascular alterations in the systemic disease.

Against this background, the present study evaluated retinal and choroidal structural parameters by OCTA in CKD patients with different stages of kidney dysfunction, and in patients treated with hemodialysis and peritoneal dialysis. In particular, it determined whether dialysis-related hemodynamic changes affect ocular measurements and characterized early microvascular changes in the superficial and deep retinal vascular plexuses, along with their systemic correlates. Comparative data on ocular structural parameters between CKD, HD and PD patients obtained with these techniques remain scarce, and clarifying these alterations may improve non-invasive monitoring of systemic microvascular dysfunction in CKD while yielding candidate biomarkers for disease-related vascular change.

## Material and methods

This cross-sectional study was carried out at the Clinic for Nephrology and Renal Replacement Therapy of the Clinical Center, University of Sarajevo, Bosnia and Herzegovina. The study population comprised patients receiving maintenance hemodialysis (HD) or peritoneal dialysis (PD) who were under regular follow-up at the dialysis unit, together with non-dialysed patients whose eGFR was either below or above 60 mL/min/1.73 m². In total, 136 eyes of 100 patients with different stages of CKD were evaluated in the cross-sectional component of the study; within this cohort, ocular measurements obtained before and after a dialysis session were available for 100 patients.

Ophthalmic evaluation was scheduled at two time points, the exact timing being dictated by the dialysis modality. In HD patients, all measurements were taken at rest, 30 minutes before the start and 30 minutes after the end of the session. In PD patients, assessments were likewise performed at rest, 15 minutes after drainage of the dialysate and again 2 hours after its refill.

Individuals whose ocular status could interfere with retinal or choroidal measurements-including significant media opacity, previous retinal surgery, advanced glaucoma, and retinal vascular disease-were excluded. The investigation was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was granted by the Ethics Committee of the Clinical Center Training and Research Hospital (Approval No. 1142), and written informed consent was obtained from every participant. A comprehensive ophthalmological examination was performed at each visit.

Clinical variables, urinalysis, and quantitative measurement of urinary albumin were collected for all participants. Albuminuria was defined as a urinary albumin excretion above 30 mg/day on a reliable 24-hour urine collection. The entire cohort was subsequently divided

into four subgroups according to two criteria: the level of kidney function (eGFR above or below 60 mL/min/ 1.73 m²) and the mode of renal replacement therapy (HD or PD).

Macular microvascular morphology was assessed with the Optovue OCTA instrument (AngioVue system, Optovue Inc., Fremont, CA, USA). Superficial and deep vascular density (SVD and DVD) were derived from 3×3 mm OCTA scans centred on the fovea. Using the built-in AngioVue software, the vascular compartment was automatically partitioned into four layers: superficial, deep, outer retinal, and choroidal. By default, SVD encompasses the vessels located between the internal limiting membrane and a plane 10 µm above the inner plexiform layer, whereas DVD covers the vasculature lying between 10 µm above the inner plexiform layer and 10 µm below the outer plexiform layer. Vessel density was expressed as the percentage of the region occupied by vessels and was computed automatically by the software for each plexus. Additional foveal metrics provided by the in–strument-foveal avascular zone (FAZ) area, FAZ peri–meter, and the presence of microaneurysms-were de–rived from the OCTA image of the inner retinal mic–rovasculature, which contains both the superficial and the deep plexus.

All computations were performed with IBM SPSS Statistics software; statistical analyses were run with SPSS version 16.0 (SPSS Inc., Chicago, IL, USA). The normality of variable distributions was examined with the Kolmogorov–Smirnov and Shapiro-Wilk tests. Normally distributed data are presented as mean ± standard deviation, whereas non-normally distributed data are summarized as median and interquartile range. Group comparisons relied on Student's t-test or the Mann–Whitney U test, depending on the distribution, and categorical variables were compared using the chi-square test. Correlations were assessed with Pearson's or Spearman's coefficients, as appropriate. A two-sided p-value below 0.05 was considered statistically significant.

## Results

### *Baseline characteristics*

The baseline characteristics of the study population are summarized in Table 1. The analysis included 136 eyes from 100 patients with CKD and/or dialysis dependence. Demographic and clinical data comprised sex, age, the presence of diabetes mellitus, and systolic and diastolic blood pressure, while hemoglobin, eGFR, urinary pro–tein excretion, and per-session ultrafiltration volume served as indicators of health status. The mean duration of a dialysis session was 4.81±0.99 hours (4.00±0.00 hours in the HD group and 5.94±0.34 hours in the PD group). Average ultrafiltration volume amounted to 2730.95±1020.83 mL, with higher values in HD patients (3085.70±1248.24 i mL) than in PD patients (2222.98 ±184.8 mL). Age did not differ significantly between the high- and low-GFR groups, nor between the HD and PD groups. Notably, the PD subgroup with albu–minuria or gross proteinuria displayed significantly higher mean plasma glucose and urinary albumin concentra–tions than the other study groups ($p < 0.001$ for both).

**Table 1.** Main clinical characteristics of patients with different stages of kidney dysfunction

| | **eGFR ≤60 mL/min (n=30)** | **eGFR >60 mL/min (n=30)** | **Hemodialysis (n=20)** | **Peritoneal dialysis (n=20)** |
|---|---|---|---|---|
| Age (years) | 66(60-74.5) | 64(56.5-71.5) | 63(58.3-72.8) | 66.5(60-73.3) |
| Gender (M/F) | 68.1%/31.9% | 70.3%/29.7% | 69.8%/30.2% | 68.3%/31.7% |
| BMI (kg/m²) | 25.27±4.16 | 24.09±2.15 | 23.85±5.63 | 24.86±4.58 |
| Smoking (yes) | 45.6% | 30.6% | 34.9% | 44.3% |
| SBP (mm Hg) | 130 (120-140) | 130(120-140) | 130(120-140) | 135(120-140) |
| DBP (mm Hg) | 80 (70-90) | 80(70-90) | 80(77.5-82.5) | 80(70-80) |
| Diabetes (yes) | 34.8% | 48.6% | 16.3% | 55.6% |
| Hb (g/L) | 109.14±20.5 | 137.54±18.8 | 114.6±17.3 | 121.2±21.9 |
| Proteinuria (g/day) | 0.51 (0.2-1.5) | 0.45(0.16-1.82) | 0.19(0.13-0.28) | 1.06(0.44-2.7) |
| Albuminuria (mg/L) | 39.5(23-247.8) | 61.5(21.5-297) | 21(16.5-27) | 204(75-282.3) |
| Cr. clear. (mL/min) | 39.7(31.7-48.9) | 74.8(65.7-94) | | |
| Dialysis session duration (h) | | | 4.00±0.00 | 5.94±0.34 |
| Ultrafiltration volume (mL) | | | 3085.70±1248.24 | 2222.98±184.8 |

*Abbreviations:* GFR-glomerular filtration rate, BMI-body mass index, SBP-systolic blood pressure, DBP-diastolic blood pressure, Hb-hemoglobin, Cr. clear.-creatinine clearance

### *Pharmacological treatment*

Table 2 presents the distribution of pharmacological treatment according to the level of kidney function. Pa–tients in the low-GFR CKD group were more frequently prescribed antihypertensive agents-in particular angio–tensin-converting enzyme inhibitors and angiotensin II type 1 receptor blockers-than their counterparts. In the dialysis groups, diuretic use was markedly more common among PD than HD patients (52.4% vs. 6.5%, p= 0.001). Systemic comorbidities and the classes of antihypertensive drugs used are detailed in Table 2.

**Table 2.** Distribution of the patients pharmacologically treated for hypertension and of other cardiovascular drugs among the groups with different stages of kidney dysfunction

| Drug class | GFR ≤60 mL/min | GFR >60 mL/min | P value | Hemodialysis | Peritoneal dialysis | P value |
|---|---|---|---|---|---|---|
| *Anti-hypertensive drugs (%)* | | | | | | |
| ACE inhibitors | 62.3 | 48.6 | 0.175 | 41.2 | 61.9 | 0.072 |
| AT1 blockers | 17.4 | 21.6 | 0.596 | 16.3 | 20.6 | 0.574 |
| Calcium antagonists | 49.3 | 51.4 | 0.839 | 55.8 | 46.0 | 0.323 |
| Diuretics | 55.1 | 40.5 | 0.154 | 6.5 | 52.4 | 0.001 |
| β-blockers | 31.9 | 29.7 | 0.819 | 17.9 | 23.3 | 0.554 |
| *Other cardiovascular drugs (%)* | | | | | | |
| Antiplatelet drugs | 30.4 | 43.2 | 0.187 | 17.2 | 23.3 | 0.681 |
| Statins | 47.8 | 54.1 | 0.541 | 41.9 | 55.6 | 0.166 |

### *OCTA-derived parameters*

OCTA-derived parameters are presented in Table 3. With respect to choroidal morphology, the low-GFR group exhibited substantially greater choroidal thinning than patients with an eGFR above 60 mL/min (p< 0.001), a difference that persisted after adjustment for antihypertensive treatment. In the parafoveal region, vascular density differed between subgroups for both the superficial and the deep plexus, with SVD being significantly lower in patients whose eGFR was ≤ 60 mL/min (p=0.03). FAZ perimeter, by contrast, did not differ between the two GFR categories (Table 3).

**Table 3.** OCTA parameters among the groups with different stages of kidney dysfunction

| Parameter | eGFR ≤ 60 mL/min | eGFR > 60 mL/min | P value |
|---|---|---|---|
| Rt total area (μm) | 274.4±10.7 | 275.7±9.7 | 0.52 |
| Rt central ring (μm) | 245.3(240.7-247.8) | 246(241.6-247.7) | 0.462 |
| Cht central ring (μm) | 286.2(246.4-290.1) | 276.6(250.2-292.6) | 0.36 |
| Cht total area (μm) | 271.2(249.7-276.7) | 270.3(264.5-275.9) | 0.59 |
| Area of FAZ (mm²) | 0.29(0.27-0.33) | 0.28(0.25-0.31) | 0.06 |
| SVD (%) | 46.6(44.9-47.9) | 47.3(45.9-49.6) | 0.03 |
| DVD (%) | 48.7(47.3-49.3) | 48.7(47.7-49.2) | 0.44 |
| MA (up to 10) | 29% | 64.9% | <0.001 |
| FAZ perimeter (μm) | 2197(2168.5-2267) | 2177(2157-2259) | 0.263 |

*Abbreviations:* GFR-glomerular filtration rate, CKD-chronic kidney disease, Rt-retinal thickness, Cht-choroidal thickness, FAZ-foveal avascular zone, SVD-superficial vascular density, DVD-deep vascular density, MA-microaneurysms

Table 4 lists the ocular parameters measured before and after the dialysis session. Prior to dialysis, the mean FAZ area was 0.3 mm² and the mean FAZ perimeter 2199 μm; mean vessel density amounted to 46.3% (SVD) and 48.1% (DVD) over the whole image, while mean total-area choroidal thickness was 266.9 μm.

**Table 4.** OCTA parameters among the groups on renal replacement therapy

| Parameter | Before dialysis Mean ± SD | Post-dialysis Mean ± SD | P value |
|---|---|---|---|
| Rt total area (μm) | 273.4(266.8-280.6) | 277.2(271.2-280.5) | 0.116 |
| Rt central ring (μm) | 244.8(240.6-247.5) | 246.3(242.2-247.9) | 0.312 |
| Cht central ring (μm) | 264.5(245.1-288.7) | 290.2(286.1-294.1) | <0.001 |
| Cht total area (μm) | 266.9(249.4-273.9) | 273.5(269.8-278.1) | 0.001 |
| Area of FAZ (mm²) | 0.3(0.3-0.34) | 0.28(0.26-0.3) | 0.03 |
| SVD (%) | 46.3(44.8-48.6) | 47.3(46.3-48.3) | 0.06 |
| DVD (%) | 48.1(47.1-48.9) | 49.1(48.6-49.4) | <0.001 |
| MA (up to 10) | 23(36.5%) | 21(48.8%) | 0.206 |
| FAZ perimeter (μm) | 2199(2166–2285) | 2177(2156-2201) | 0.009 |

*Abbreviations:* GFR-glomerular filtration rate, CKD-chronic kidney disease, Rt-retinal thickness, Cht-choroidal thickness, FAZ-foveal avascular zone, SVD-superficial vascular density, DVD-deep vascular density, MA-microaneurysms

Following dialysis, the corresponding values were 0.28 mm² for FAZ area, 2177 μm for FAZ perimeter, 47.3% for SVD, 49.1% for DVD, and 273.5 μm for total-area choroidal thickness (Table 4).

### Comparison between dialysis modalities

Changes in ocular and systemic parameters from before to after the session were compared between HD and PD patients using the Mann–Whitney U test. The two modalities differed significantly with respect to the change in FAZ area (p=0.04) as well as to the changes in SBP (p<0.001), DBP (p=0.017), and intraocular pressure (p=0.006). In contrast, none of the OCTA-derived retinal microvascular measures-SVD, DVD, FAZ metrics, or choroidal thickness-changed significantly between HD and PD patients (all p >0.05, Table 5).

**Table 5.** Comparison of parameter changes between HD and PD

| Parameter | HD Δ (Mean ± SD) | PD Δ (Mean ± SD) | P value |
|---|---|---|---|
| ΔFAZ area (mm²) | 0.0039±0.0909 | -0.0191±0.074 | 0.047 |
| ΔFAZ perimeter (mm) | -0.0067±0.315 | -0.0228±0.325 | 0.986 |
| ΔSVD whole (%) | 0.24±3.92 | 0.23±2.31 | 0.986 |
| ΔDVD whole (%) | 0.54±5.03 | -0.30±3.24 | 0.206 |
| ΔChoroidal thickness(μm) | 6.59±20.36 | 3.31±24.59 | 0.516 |
| ΔSystolic BP (mm Hg) | 17.22±18.68 | -4.20±11.77 | <0.001 |
| ΔDiastolic BP (mm Hg) | 8.82±10.64 | 2.83±10.98 | 0.017 |

Correlation analyses. Spearman correlation analysis disclosed a moderate negative association between the change in choroidal thickness and the change in SBP (r=-0.372, p<0.001), and a moderate positive association between dialysis session duration and the change in choroidal thickness (r=0.320, p=0.003). Ultrafiltration volume correlated weakly and negatively with the change in whole-image DVD (r=-0.239, p=0.028) and with no other OCTA parameter (all p>0.05; Table 6). In bivariate analyses, kidney function and albuminuria emerged as the strongest correlates of choroidal measures (Table 6). Choroidal thickness-but not retinal thickness-was significantly associated with eGFR, as were SVD and DVD. Among the OCTA metrics, parafoveal vascular density in both plexuses was inversely related to albuminuria, and foveal SVD and DVD, FAZ area, and FAZ perimeter were all associated with eGFR and albuminuria. In subjects with positive albuminuria, urinary albumin excretion was inversely correlated with choroidal thickness in the central ring and in the total area. Associations with the remaining clinical variables were inconsistent.

**Table 6.** Correlations of the chorioretinal parameters assessed by OCTA in the overall study population

| OCTA parameter | GFR (rho) | Albuminuria (rho) | Hb (rho) | SBP (rho) | DBP (rho) |
|---|---|---|---|---|---|
| Rt total area (μm) | 0.180 | -0.223* | 0.254** | -0.197* | 0.072 |
| Cht total area (μm) | 0.187 | -0.398** | 0.232* | -0.083 | 0.168 |
| Area of FAZ (mm²) | -0.26** | 0.291** | -0.27** | 0.168 | -0.047 |
| SVD (%) | 0.32** | -0.275** | 0.352** | -0.095 | 0.143 |
| DVD (%) | 0.203* | -0.490** | 0.185 | -0.088 | 0.114 |
| FAZ perimeter (mm) | -0.233* | 0.389** | -0.081 | -0.103 | -0.058 |

*Abbreviations:* GFR-glomerular filtration rate, Hb-hemoglobin, SBP-systolic blood pressure, DBP-diastolic blood pressure, Rt-retinal thickness, Cht-choroidal thickness, FAZ-foveal avascular zone, SVD-superficial vascular density, DVD-deep vascular density, *p<0.05. **p<0.01

## Discussion

The retinal and choroidal microvasculature is increasingly regarded as a readily accessible surrogate of systemic microvascular health. Because the retinal circulation shares numerous anatomical and physiological features with other end-organ capillary beds, non-invasive imaging with OCT and OCTA offers a means of examining systemic vascular alterations in vivo. In CKD and ESRD, systemic microvascular dysfunction, chronic inflammation, endothelial injury, and metabolic derangement act in concert to produce widespread vascular damage that may well extend to the ocular circulation.
Two principal findings emerged from this study. First, CKD was associated with retinal thinning and with a progressive decline in retinal-choroidal vascular density as kidney function deteriorated. Second, the microvasculature of different retinal layers appeared to respond differentially to systemic comorbidity.

It is well established that long-term microvascular structural and functional changes accompany diabetes mellitus, and comparable alterations are encountered in the retina, in neural tissue, and in the kidney. Whereas the progression of CKD is traditionally monitored by invasive means-most often kidney biopsy-retinal microvascular abnormalities may serve as a window onto systemic microangiopathy in renal vascular disease and arterial hypertension, and their objective quantification has become a topic of active investigation [10]. The choroid, despite being a highly vascular structure with a key role in ocular volume regulation and metabolism, has received considerably less attention in this respect [11]. Earlier epidemiological work has linked CKD to a higher prevalence of visual impairment and ocular disease [9,12,13]. OCTA enables repeatable, high-resolution evaluation of retinal and choroidal volume and thickness [3], and recent studies have applied it to the non-invasive interrogation of ocular microcirculatory

flow without the need for contrast agents [14]. From a nephrological perspective, OCTA therefore represents a readily available instrument for the rapid detection of retinal microvascular alterations that may mirror sys–temic circulatory and renal status.

Only a limited number of studies have so far compared OCTA metrics across stages of CKD. In our cohort, patients with an eGFR above 60 mL/min differed sig–nificantly from those with lower eGFR values in se–veral microvascular parameters, including FAZ area, FAZ perimeter, and radial peripapillary capillary density.

Hemodialysis, although indispensable for the elimination of metabolic waste and excess fluid, exposes patients to rapid hemodynamic and osmotic fluctuations that may affect both the systemic and the ocular circulation [12]. Ultrafiltration and osmotic shifts during a session provoke swift changes in intravascular volume and blood pressure, with the potential to disturb ocular perfusion. Earlier studies have demonstrated that such physiological stress can induce transient structural and vascular changes in the retina and choroid. For instance, Chen *et al.*, described increased macular retinal nerve fiber layer thickness together with reduced choroidal thickness shortly after hemodialysis, attributing these changes to rapid fluid redistribution and osmotic shifts [13]. Consistent with this, several OCT and OCTA investigations have reported a decrease in subfoveal choroidal thickness after HD sessions, particularly in the temporal and nasal regions; a pooled self-controlled case series by Su *et al*., confirmed a moderate but con–sistent reduction across studies [14]. Beyond structural effects, dialysis-related circulatory stress may also compromise ocular perfusion itself, as reflected in re–ports of enlarged choriocapillaris non-perfusion areas after HD despite largely unaltered retinal vascular density [13,16]. Taken together, these observations su–ggest that the choroidal circulation is more vulnerable to the hemodynamic stress of dialysis than the retinal vasculature, which benefits from stronger autoregu–latory capacity.

Our data are in partial agreement with those of Balmforth *et al.*, [23], who demonstrated a direct relationship between GFR and choroidal thickness, an inverse relationship between choroidal thickness and proteinuria, and thinning of both retinal and choroidal layers in CKD patients compared with healthy and hypertensive controls. In contrast with that study, we did not detect a correlation between retinal thickness and estimated kidney function. It is conceivable that the relationship between GFR and retinal thickness evolves progressively as renal function declines.

A substantial body of evidence links retinal microvascu–lar abnormalities and vessel caliber changes to renal impairment in CKD [17,18]. In one study of 184 diabetic patients, retinal capillary rarefaction was shown to correspond to coexisting microcirculatory damage in the kidney [22]. Furthermore, the OCTA findings mirrored earlier histopathological observations of endothelial alterations and capillary dropout in diabetic retinas. In that cohort, the mean and the largest ten intercapillary areas correlated significantly with glomerular filtration, and previous reports had already demonstrated associations between OCTA metrics such as FAZ area, FAZ perimeter, and vessel density and diabetic retinopathy. In the present study, FAZ area, FAZ perimeter, and choroidal capillary flow area were markedly modified with advancing disease.

Our findings both corroborate and extend the existing literature data. Comparing OCTA parameters between HD and PD patients, the most striking observation was a significant difference in choroidal thickness between the two modalities, suggesting that HD may elicit more pronounced acute structural changes in the macula. Most OCTA-derived vascular indices-FAZ area and perimeter, and vessel density in both capillary plexu–ses-neither differ between the groups, nor had changed choroidal thickness. These results are consistent with the physiological contrast between the two treatments: HD is characterized by intermittent sessions with re–latively rapid fluid removal and pronounced hemody–namic swings, whereas PD achieves slower, more continuous ultrafiltration. The sharper intravascular volume and osmotic shifts experienced by HD patients could therefore be expected to translate into larger short-term structural changes in retinal tissue. Accor–dingly, the absence of any association between ultra–filtration volume and ocular parameters in our analysis suggests that the observed retinal changes relate chiefly to the speed of hemodynamic shifts rather than to the absolute amount of fluid removed.

Notably, in the CKD groups albuminuria, unlike eGFR, showed significant inverse associations with retinal and choroidal thickness. Our study design did not per–mit an explanation of this divergent behavior of eGFR and albuminuria. Nevertheless, available evidence in–dicates that microalbuminuria is more closely tied to the progression of diabetic retinopathy than a moderate reduction in eGFR [19]. It is also worth emphasizing the independent association we observed between eGFR and retinal vascular density, evaluated as parafoveal SVD and DVD by OCTA. Although the cross-sectional design precludes causal inference, one plausible inter–pretation is that the oxidative stress, inflammation, and endothelial damage inherent to CKD from its earliest stages intensify as kidney function worsens, thereby explaining the relationship between choroidal attenuation and lower eGFR, particularly in albuminuric patients [16].

Several limitations deserve mentioning. The sample size was relatively small, which may have limited the statistical power to detect subtle differences between dialysis modalities. The cross-sectional design precludes evaluation of the long-term ocular consequences of dialysis therapy and of the direction of the observed associations, where no longitudinal follow-up data were

available. Finally, although systemic dialysis-related parameters such as ultrafiltration volume and session duration were examined, they were not significantly associated with most ocular imaging variables; nevertheless, transient hemodynamic fluctuations during dialysis cannot be excluded as a source of residual confounding. Consequently, our results may reflect early microvascular alterations rather than late-stage retinopathy.

## Conclusion

OCTA offers an attractive, non-invasive means of exploring the interrelation between the retinal-choroidal circulation and other vascular beds. The present study demonstrates that patients with CKD exhibit a significant reduction in retinal microvascular density, affecting both the superficial and deep plexuses. Furthermore, although most OCTA-derived retinal microvascular parameters remained stable when HD and PD patients were compared, macular thickness changes appeared to differ between the modalities, in parallel with the greater hemodynamic and osmotic stress of intermittent HD relative to the gradual fluid removal achieved by PD. These observations reaffirm the close coupling between ocular microcirculatory alterations and kidney function, and provide insight into the subclinical retinal changes associated with the systemic disease. Further studies are required to clarify the mechanisms underlying our findings and to establish whether imaging information derived from OCTA carries prognostic value for the progression of CKD.

*Conflict of interest statement.* None declared.

## References

1. Kidney Disease: Improving Global Outcomes (KDIGO) CKD Work Group. KDIGO 2024 clinical practice guideline for the evaluation and management of chronic kidney disease. *Kidney Int Suppl* 2024; 105(4S): S117-S314.
2. Patel PP, Egodage T. Failing kidneys: renal replacement therapies in the ICU. *Trauma Surg Acute Care Open* 2024; 9(Suppl 2): e001381.
3. Goodbred AJ, Langan RC. Chronic kidney disease: prevention, diagnosis, and treatment. *Am Fam Physician* 2023; 108(6): 554-561.
4. Zhang Y, Yu C, Li X. Kidney aging and chronic kidney disease. *Int J Mol Sci* 2024; 25(12): 6585.
5. Spasiano A, Benedetti C, Gambaro G, Ferraro PM. Predictive models in chronic kidney disease: essential tools in clinical practice. *Curr Opin Nephrol Hypertens* 2024; 33(2): 238-246.
6. Levin A, Ahmed SB, Carrero JJ, *et al*. Executive summary of the KDIGO 2024 clinical practice guideline for the evaluation and management of chronic kidney disease: known knowns and unknowns. *Kidney Int* 2024; 105(4): 684-701.
7. Fekrazad S, Hassanzadeh G, Mousavi A, *et al*. Optical coherence tomography measurements alteration in patients with end-stage renal disease after hemodialysis. *Ophthalmic Res* 2025; 68: 503-520.
8. Bineshfar N, Farjam M, Sharafi F, Changizi F. Association of chronic kidney disease and retinal changes measured by optical coherence tomography: a systematic review and meta-analysis. *Invest Ophthalmol Vis Sci* 2024; 65: 5536.
9. Basiony AI, Atta SN, Dewidar NM, Zaky AG. Association of chorioretinal thickness with chronic kidney disease. *BMC Ophthalmol* 2023; 23: 55.
10. Majithia S, Chong CCY, Chee ML, *et al*. Associations between chronic kidney disease and thinning of neuroretinal layers in multiethnic Asian and White populations. *Ophthalmol Sci* 2024; 4: 100353.
11. Choi SU, Oh JY, Kim JT. Correlations between choroidal thickness and renal function in patients with retinal vein occlusion. *Sci Rep* 2020; 10: 16865.
12. Farrah TE, Dhillon B, Keane PA, *et al*. The eye, the kidney, and cardiovascular disease: old concepts, better tools, and new horizons. *Kidney Int* 2020; 98: 323-342.
13. Chen H, Zhang X, Shen X. Ocular changes during hemodialysis in patients with end-stage renal disease. *BMC Ophthalmol* 2018; 18: 208.
14. Su Z, Mao Y, Qi Z, *et al*. Impact of hemodialysis on subfoveal choroidal thickness measured by optical coherence tomography: a systematic review and a pooled analysis of self-controlled case series. *Ophthalmol Ther* 2023; 12: 2265-2280.
15. Zegrari S, Mouallem A, Audard V, *et al*. Optical coherence tomography angiography analysis of changes in the retina and the choroid after hemodialysis for end-stage kidney disease. *Int Ophthalmol* 2023; 43: 4473-4479.
16. Shoshtari FS, Biranvand S, Rezaei L, *et al*. The impact of hemodialysis on retinal and choroidal thickness in patients with chronic renal failure. *Int Ophthalmol* 2021; 41: 1763-1771.
17. Atilgan CU, Guven D, Akarsu OP, *et al*. Effects of hemodialysis on macular and retinal nerve fiber layer thicknesses in non-diabetic patients with end-stage renal failure. *Saudi Med J* 2016; 37: 641-647.
18. Mustafar R, Hishamuddin KAM, Mohd R, *et al*. Retinal changes and cardiac biomarker assessment in relation to chronic kidney disease: a single centre study. *BMC Nephrol* 2023; 24: 338.
19. Tang M, Lin L, Liu S, *et al*. Correlation between fundus damage and renal function deterioration in chronic kidney disease patients. *Kidney Blood Press Res* 2024; 49: 1003-1012.
20. He K, Liu S, Shi J, *et al*. The effect of long-term hemodialysis on diabetic retinopathy observed by swept-source optical coherence tomography angiography. *BMC Ophthalmol* 2024; 24: 334.
21. Mullaem G, Rosner MH. Ocular problems in the patient with end-stage renal disease. *Semin Dial* 2012; 25: 403-407.
22. Cheung CY, Tang F, Ng DS, *et al*. The relationship of quantitative retinal capillary network to kidney function in type 2 diabetes. *Am J Kidney Dis* 2018; 71(6): 916-918.
23. Balmforth C, van Bragt JJ, Ruijs T, *et al*. Chorioretinal thinning in chronic kidney disease links to inflammation and endothelial dysfunction. *JCI Insight* 2016; 8(1): 20.