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RESEARCH ARTICLE

Cardio-ocular syndrome: Retinal microvascular changes in acutely decompensated heart failure

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Aims To investigate the changes in retinal microvasculature by contemporary imaging techniques during episodes of acute decompensated heart failure (ADHF) and following recompensation compared to age-matched controls without known cardiac or retinal disease.

Methods and results Adult patients hospitalized with a primary diagnosis of ADHF, regardless of left ventricular ejection fraction (LVEF) and treated with a minimum dose of 40 mg of intravenous furosemide or equivalent were included. Transthoracic echocardiography was conducted in all patients. Eye examinations were performed out within the initial 24 h after admission and after recompensation before discharge. All eyes underwent a general examination, including a best corrected visual acuity test, dilated fundoscopy, spectral-domain optical coherence tomography (OCT) as well as OCT angiography (OCT-A). In addition, 40 participants without documented cardiac or retinal diseases served as controls. Forty patients with ADHF (mean age 78.9 ± 8.8 years; 32% female) with a mean LVEF of 43 ± 12.8% were included. All patients were treated with intravenous diuretics for a median of 4.3 ± 2.8 days. There was a significant reduction in N-terminal pro-B-type natriuretic peptide from baseline up to discharge (10 396 [interquartile range 6410] vs. 6380 [interquartile range 3933] pg/ml, $p \leq 0.001$) and inferior vena cava diameters (2.13 ± 0.4 vs. 1.63 ± 0.3 cm, $p = 0.003$). Compared to the control group, patients with ADHF showed on admission impaired visual acuity (0.15 ± 0.1 vs. 0.35 ± 0.1 logMAR, $p < 0.001$), reduced macular vessel density (18.0 ± 1.9 vs. 14.3 ± 3.6 mm/mm^2, $p < 0.001$) and perfusion density (42.6 ± 3.2 vs. 35.2 ± 9.7%, $p < 0.001$). After recompensation, the mean overall vessel density and mean overall perfusion density were markedly increased at discharge (14.3 ± 3.6 vs. 19.7 ± 2.6 mm/mm^2, $p = 0.001$, and 35.2 ± 9.7 vs. 39.2 ± 6.5%, $p = 0.005$, respectively). The mean diameter of the superior temporal retinal vein at admission was significantly larger compared to the control group (136 ± 19 vs. 124 ± 22 µm, $p = 0.008$) and decreased significantly to 122 ± 15 µm at discharge ($p < 0.001$).

Conclusion This analysis revealed a remarkable reversible change in retinal microvasculature after ADHF. This could provide a valuable evidence for use of OCT-A in the assessment of overall microperfusion and haemodynamic status in patients with acute heart failure.

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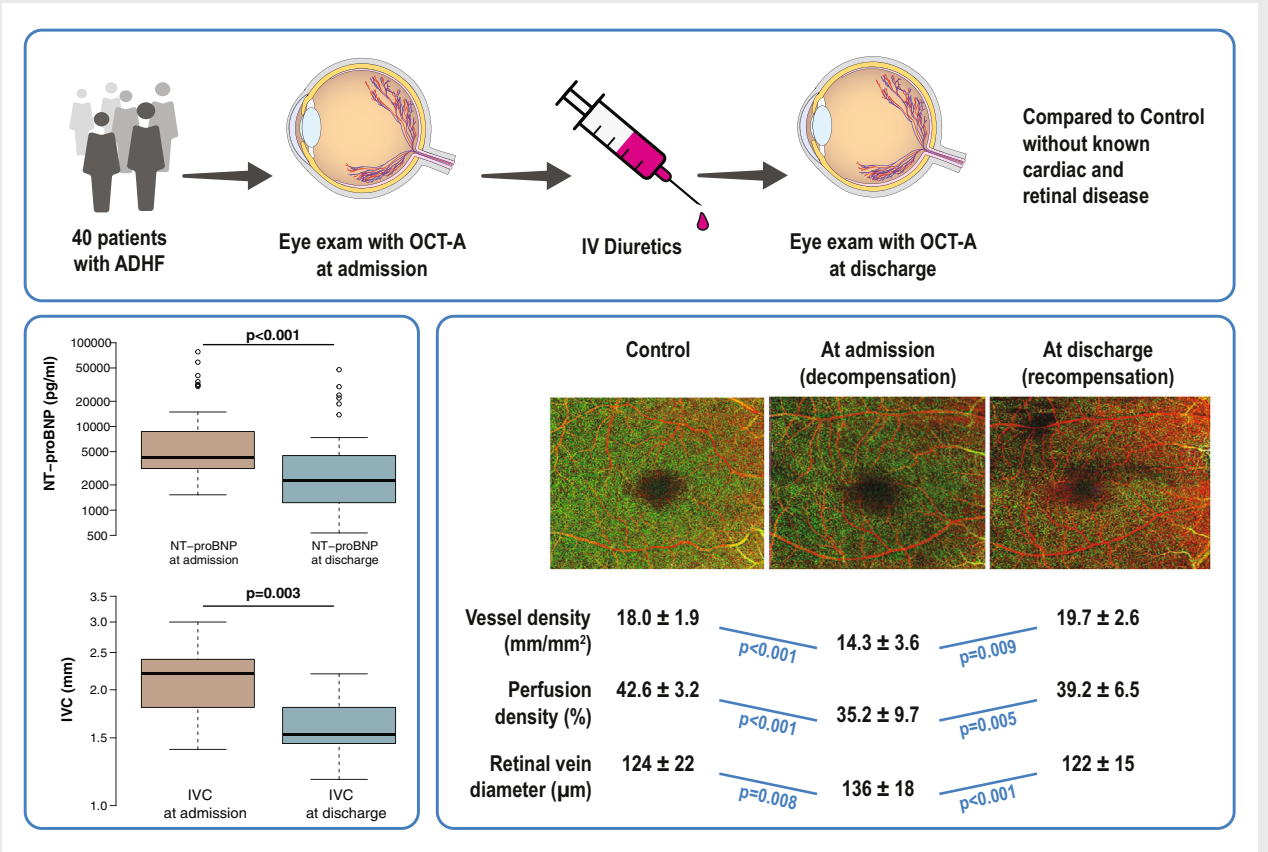
Graphical Abstract



Summary of the key background and findings of the study. ADHF, acute decompensated heart failure; IV, intravenous; IVC, inferior vena cava; NT-proBNP, N-terminal pro-B-type natriuretic peptide; OCT, optical coherence tomography; OCT-A, optical coherence tomography angiography.

Keywords Acute heart failure • Congestion • Retinal microvascular changes • Optical coherence tomography angiography

Introduction

Heart failure (HF) continues to be one of the cardiovascular syndromes experiencing rapid growth of prevalence accompanied by a high mortality rate.[1] Congestion is the leading cause of hospitalization in patients with acute decompensated HF (ADHF).[2] Accumulation of fluid that leads to congestion begins in intravascular compartments and continuously increased hydrostatic pressures in the capillary vessels subsequently lead to tissue congestion.[2,3] The majority of patients with congestive HF present with both a combination of intravascular and tissue congestion.[2] When patients experience fluid overload, there is an elevation in venous pressure that is transmitted back to the efferent arterioles. Consequently, this condition contributes to impaired organ perfusion, ultimately resulting in organ damage.[4] This phenomenon has been previously observed in various organs, including the kidney, liver, intestines and brain.[2–4] Nevertheless, the acute effects of congestion on the eyes remain unidentified.

The eye is often affected by systemic diseases,[5,6] and previous research suggests that retinal imaging can effectively reveal structural and functional abnormalities in the microcirculation associated with left ventricular (LV) remodelling.[7–11] Contemporary retinal imaging provides a non-invasive method to directly assess the retinal microvasculature, serving as a representation of systemic microcirculation and has been speculated to provide insights into the function of various organs, including the heart.[7,12]

Although optical coherence tomography angiography (OCT-A) is widely used in retinal imaging, this newer technology has not been adequately studied in HF. Moreover, no study has explored retinal changes during ADHF.

Therefore, we aimed to investigate the functional and morphological choroidal and retinal changes utilizing OCT and OCT-A during episodes of ADHF and following recompensation in combination with cardiac imaging and biomarkers compared to a control group without known cardiac or retinal diseases.

Methods

This observational study on retinal microvascular changes in patients with ADHF and controls was conducted at Saarland University Hospital, Homburg, Germany. Adult patients hospitalized with a primary diagnosis of ADHF, regardless of LV ejection fraction (LVEF) and treated with a minimum dose of 40 mg of intravenous furosemide or equivalent were studied. To be included, patients had to have dyspnoea and at least two of the following four signs: (i) congestion on chest x-ray, (ii) rales on chest auscultation, (iii) clinically relevant oedema (e.g. ≥1+ on a 0 to 3+ scale), (iv) dilated inferior vena cava (IVC). Additionally, N-terminal pro-B-type natriuretic peptide (NT-proBNP) level had to be >1000 pg/ml.

Key cardiac exclusion criteria included cardiogenic shock, current hospitalization for ADHF primarily caused by acute myocardial infarction, major cardiac surgery, or patients requiring dialysis. Additional exclusion criteria were patients who previously received a cardiac transplant, were expected to receive a transplant during the course of the study, had planned palliative care for HF, or were currently using or planning to use a LV assist device or intra-aortic balloon pump, or outpatient inotropic support.

Patients underwent recompensation through the administration of standard care in accordance with the prevailing local and regional guidelines as determined by their treating clinicians. Transthoracic echocardiographic examinations were conducted as part of routine clinical admission procedures, utilizing two-dimensional and colour Doppler echocardiography techniques performed by experienced cardiologists in accordance with current guidelines.[13] The study protocol was approved by the local ethics committee (Kenn-Nr. 63/22).

Ocular analysis

Eye examinations were carried out within 24–48 h after admission and during the last 24 h preceding discharge. For both examinations, all eyes underwent a general eye examination, including a decimal best corrected visual acuity test, dilated fundoscopy, spectral-domain OCT (SD-OCT) including infrared reflectance (IR) (Heidelberg Engineering, Heidelberg, Germany) as well as OCT-A (Cirrus HD-OCT model 5000; Carl Zeiss Meditec AG, Jena, Germany).

The eye with the best corrected visual acuity of each patient was included. All eyes with a history of vitreoretinal disease or history of previous retinal treatments with intravitreal injections, laser or retinal surgery were excluded. Since the quality of OCT-A images is crucial for reliable quantitative image evaluation, only OCT-A images with a signal strength above 6/10 were included in our study. In this study, all parameters measured by OCT and OCT-A exams were analysed.

Main ocular outcome measures included

- Best corrected visual acuity test as measured on a Snellen decimal scale and converted to logMAR. LogMAR was chosen because it is the most commonly used measurement in the literature. When using the logMAR chart, visual acuity is scored with reference to the logarithm of the minimum angle of resolution. A subject who can resolve details as small as 1 min of visual angle scores logMAR 0, since the base-10 logarithm of 1 is 0; a subject who can resolve details as small as 2 min of visual angle scores logMAR 0.3, since the base-10 logarithm of 2 is approximately 0.3. The 6/6 Snellen visual acuity, which corresponds to a logMAR value of zero, can be regarded as complete visual acuity. Snellen visual acuity 6/60, on the other hand, corresponds to a logMAR value of 1.0 (i.e. 10 times worse than 6/6).
- Intraocular pressure as measured using Goldmann applanation tonometry.

Spectral-domain optical coherence tomography parameters

The volumetric SD-OCT scans of the macula included 19 parallel B-scans with a spacing of 240 µm and a pattern size of 20 × 15° with the automatic real-time repeat function turned on.

- Central macular thickness as measured by SD-OCT and defined as the mean retinal thickness (µm) between the internal limiting membrane and the basement membrane of Bruch in the central 1 mm of the fovea. The central macular thickness could be affected by anatomical and metabolic factors like systolic blood pressure, blood glucose, and so forth.
- Subfoveal choroidal thickness as measured manually on an enhanced depth imaging OCT (EDI-OCT) scan and defined as the vertical distance (µm) from the hyperreflective line of Bruch's membrane to the hyperreflective line of the inner surface of the sclera. The results of two OCT readers were masked, and the average of the subfoveal choroidal thickness they measured was used for analysis. The choroid is a highly perfused vascular layer of the eye, thus the choroidal thickness acts as a potential biomarker for cardiovascular diseases.
- Retinal vessel diameters: the diameters of the superior temporal retinal artery and vein were determined on IR images by scanning a circular area with a diameter of 3.42–4.04 mm in the centre of the optic disc and then measured with spectralis software using the manual meter.[14,15]

Optical coherence tomography angiography parameters

- Vessel density in mm/mm^2 defined as the total length of perfused vasculature per unit area in the region of measurement.
- Perfusion density in (%) defined as the total area of perfused vasculature per unit area in the region of measurement, standing for the proportion of area covered by blood vessels.

All scans were taken using AngioPlex technology, which employs the optical microangiography algorithm. A 6 × 6 mm^2 scan was performed. En-face images of the retinal vasculature were generated for the superficial capillary plexus, which allowed sizing of the foveal avascular zone as an area within the central boundary of the capillary network and measurement of vessel density, perfusion density in the superficial capillary plexus.

The measurement area of the 6 × 6 mm^2 scan was divided into three subfields according to the Early Treatment Diabetic Retinopathy Study (ETDRS): the central subfield, the outer ring and the inner ring.[13]

The central subfield was circular and had a diameter of 1 mm at the centre of the fovea. The inner ring was a ring with an outer diameter of 3 mm and an inner diameter of 1 mm centred on the fovea. The outer ring was a ring with an outer diameter of 6 mm and an inner diameter of 3 mm centred on the fovea.

All IR, SD-OCT, OCT-A scans were reviewed and checked for artefacts and segmentation errors by two independently co-authors (ADA and EWB) as retinologists.

In addition, 40 asymptomatic participants without documented cardiac or retinal diseases served as control. Control group patients were matched based on age and gender criteria. They were recruited from the eyelid or cataract clinic, having undergone either eyelid or cataract surgery at least 1 month prior to the study. Each participant underwent a comprehensive clinical examination, along with assessments using macular OCT and OCT-A.

Statistical analysis

Continuous data are presented as mean ± standard deviation, skewed continuous parameters were expressed as median (interquartile range [IQR] defined as Q1–Q3). Categorical variables were analysed using χ^2 test or Fisher's exact test as appropriate. Continuous characteristics were tested with one-way analysis of variance as omnibus and Student's *t*-test or Welch's test for unequal variances post hoc. Non-normally distributed data were compared using the Wilcoxon rank sum test (also known as the Mann–Whitney U test) for unpaired data. For non-normally distributed paired data, we used the Wilcoxon signed-rank test. Normality was assessed visually by quantile–quantile plots. To analyse the association between baseline and discharge parameters, binary logistic regression analysis was used. Categorical data were summarized as frequencies and percentages and were compared using χ^2 test. Statistical analyses were performed using SPSS statistical software (version 22.0; SPSS Inc., Chicago, IL, USA). A two-tailed $p < 0.05$ was considered statistically significant.

Results

Between August 2022 and August 2023, 40 patients with ADHF (mean age 78.9 ± 8.7 years; 32% female) were included. *Table 1* depicts clinical characteristics, laboratory parameters and concomitant medication. Patients in the study group were compared to 40 age and sex propensity score-matched individuals without known cardiac or retinal diseases (mean age 77.8 ± 8.7 years; 35% female). Patients with ADHF had a mean LVEF of 43 ± 12.8% (42% with HF with reduced ejection fraction) and 50% had a history of coronary artery disease. The mean NT-proBNP was 10 396 pg/ml (IQR 6410 pg/ml). All patients had dilated IVCs with a mean diameter of 2.13 ± 0.4 cm and were congested on chest x-ray. All patients were treated with intravenous diuretics for a median of 4.3 ± 2.8 days. The median (IQR) time from hospital admission to discharge was 8.5 (5–10) days.

From baseline up to discharge, NT-proBNP decreased from 10 396 (IQR 6410) to 6380 (IQR 3933) pg/ml ($p < 0.001$) and IVC diameters from 2.13 ± 0.4 to 1.63 ± 0.3 cm ($p = 0.003$) (*Figure 1*).

Visual acuity and intraocular pressure

The mean time between the first and second eye examination was 5.9 ± 3.6 days.

Table 1 Baseline characteristics of the study patients

Age (years)	78.9 ± 8.76
Male sex, *n* (%)	27 (68)
LVEF	
Mean (%)	43 ± 12.8
≤40%, *n* (%)	17 (42.5)
Body mass index (kg/m^2)	29.9 ± 6.1
NYHA class, *n* (%)	
III	28 (70)
IV	12 (30)
Coronary artery disease, *n* (%)	20 (50)
Hypertension, *n* (%)	33 (82.5)
Diabetes mellitus, *n* (%)	9 (22.5)
Atrial fibrillation, *n* (%)	26 (65)
COPD, *n* (%)	6 (15)
Peripheral artery disease, *n* (%)	3 (7.5)
Stroke/TIA, *n* (%)	3 (7.5)
Implantable cardioverter-defibrillator, *n* (%)	5 (12.5)
Cardiac resynchronization therapy, *n* (%)	3 (7.5)
Blood values at admission, *n* (%)	
Haemoglobin (mg/dl)	12 ± 3.09
White blood count (10^9/L)	7.3 ± 2.9
Sodium (mmol/L)	137.6 ± 5.3
Potassium (mmol/L)	4.3 ± 5.1
ASAT (U/L)	33.9 ± 19.2
ALAT (U/L)	30.4 ± 24
eGFR (ml/min/1.73 m^2)	39.6 ± 16.4
NT-proBNP (pg/ml), median (IQR)	10 396 (6410)
CRP (mg/dl)	23.6 ± 12.8
TSH (mIU/ml)	2.1 ± 2
Treatment, *n* (%)	
Beta-blocker	33 (85)
ACEi, ARB, or ARNI	36 (90)
MRA	31 (77.5)
SGLT2 inhibitors	34 (85)

ACEi, angiotensin-converting enzyme inhibitor; ALAT, alanine aminotransferase; ARB, angiotensin receptor blocker; ASAT, aspartate aminotransferase; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; eGFR, estimated glomerular filtration rate; IQR, interquartile range; LVEF, left ventricular ejection fraction; MRA, mineralocorticoid receptor antagonist; NT-proBNP, N-terminal pro-B-type natriuretic peptide; NYHA, New York Heart Association; SGLT2, sodium–glucose cotransporter 2; TIA, transient ischaemic attack; TSH, thyroid-stimulating hormone.

Mean best corrected visual acuity (logMAR) did not change significantly between the two eye examinations at admission and discharge (0.35 ± 0.1 vs. 0.33 ± 0.2, $p = 0.53$), but was significantly better in the control group compared to both examinations at admission and discharge (0.15 ± 0.1 vs. 0.35 ± 0.1, $p < 0.001$ and 0.15 ± 0.1 vs. 0.33 ± 0.2, $p = 0.001$ respectively) (*Figure 2A*).

Compared to the control group, there was no difference in intraocular pressure during acute decompensation (13.4 ± 3.2 vs. 13.6 ± 1.9 mmHg, $p = 0.73$). However, compared to the first examination at admission, the mean intraocular pressure at discharge decreased significantly from 13.4 ± 3.2 to 11.6 ± 2.7 mmHg ($p < 0.001$) without anti glaucoma drops topically applied (*Figure 2B* and *Table 2*).

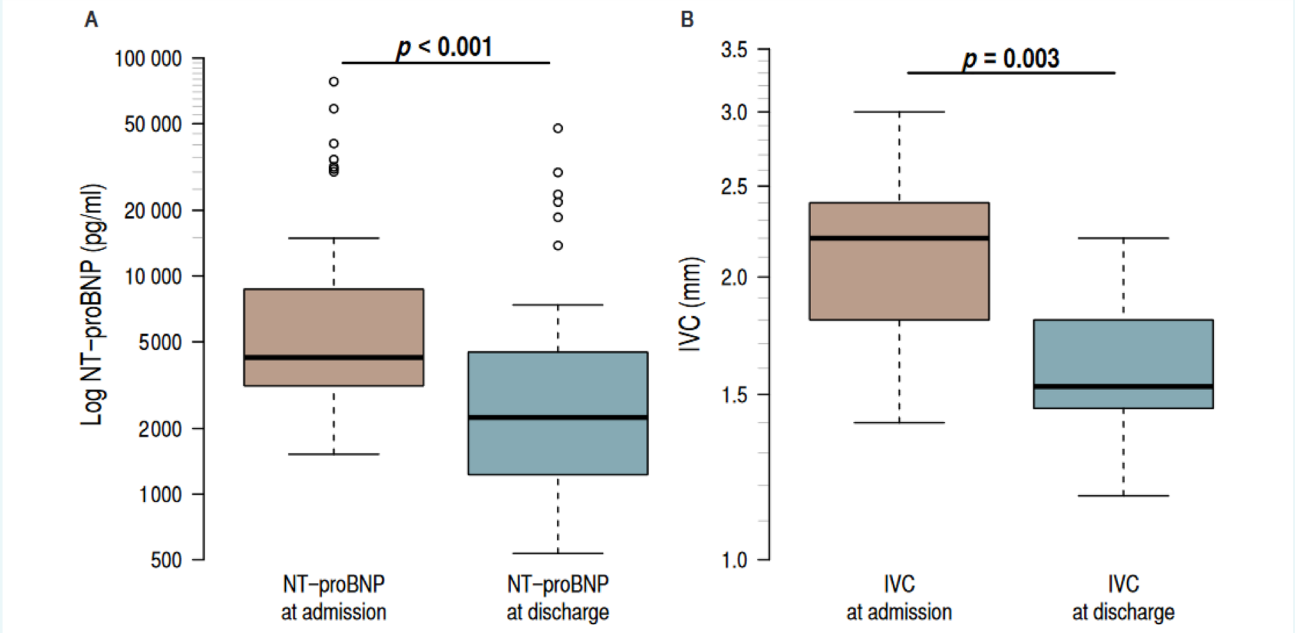


Figure 1 (*A*) Median N-terminal pro-B-type natriuretic peptide (NT-proBNP) and (*B*) inferior vena cava (IVC) diameters at admission and at discharge.

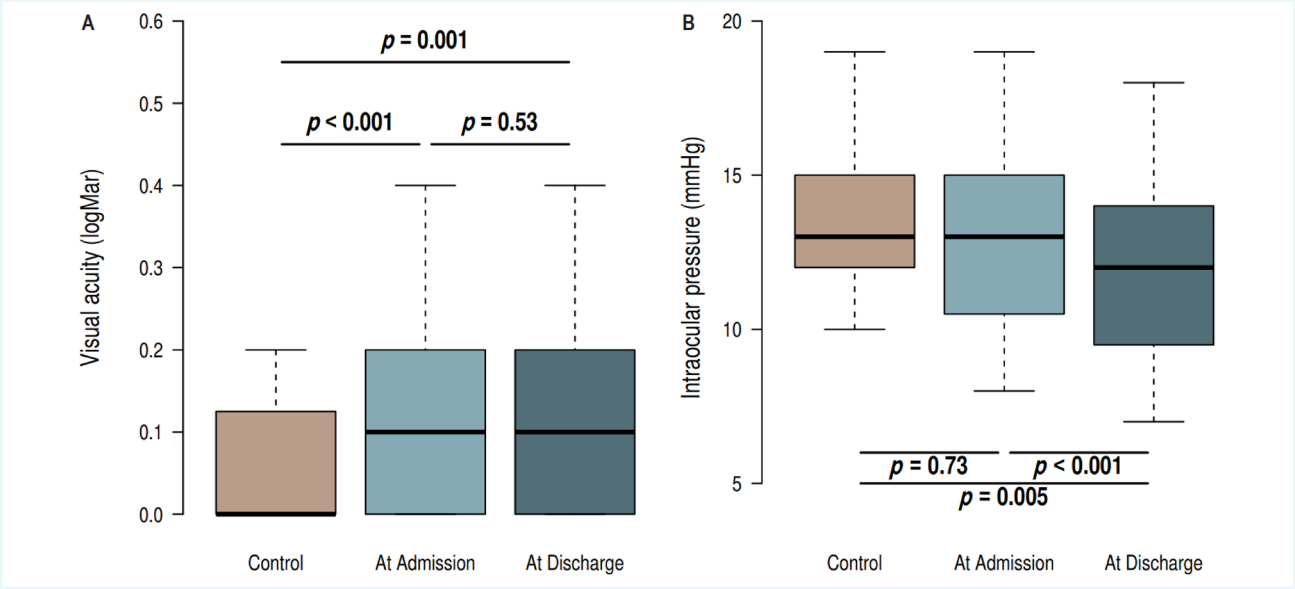


Figure 2 (*A*) The mean best-corrected visual acuity and (*B*) mean intraocular pressure at admission and at discharge compared to that of the control group.

Vessel and perfusion density

At admission, the overall vessel density was significantly lower than that of the control group (14.3 ± 3.6 vs. 18.0 ± 1.9 mm/mm^2, $p < 0.001$). However, there was a significant increase in mean overall vessel density observed at discharge compared to the initial examination at admission (14.3 ± 3.6 vs. 19.7 ± 2.6 mm/mm^2, $p = 0.009$). Notably, following recompensation, no significant difference in vessel density was found compared to the control group (19.7 ± 2.6 vs. 18.05 ± 1.9 mm/mm^2, $p = 0.65$) (*Figure 3A,B*).

Likewise, the overall perfusion density at admission was significantly lower than that of the control group (35.2 ± 9.7 vs. 42.6 ± 3.2%, $p < 0.001$). There was a notable increase in mean overall perfusion density at discharge compared to the initial examination at admission (35.2 ± 9.7 vs. 39.2 ± 6.5%, $p = 0.005$).

Table 2 Ocular examined parameter at the first examination upon admission and at the second examination before discharge

Ocular parameters	CG ($n = 40$)	ADHF group ($n = 40$)		*p*-value		
		E1	E2	E1–E2	CG-E1	CG-E2
BCVA (logMAR)	0.15 ± 0.1	0.35 ± 0.1	0.33 ± 0.2	0.53	<0.001	0.001
IOP (mmHg)	13.6 ± 1.9	13.4 ± 3.2	11.6 ± 2.7	<0.001	0.73	0.005
OCT-A parameters						
Signal strength index (/10)	9.7 ± 0.8	8.5 ± 1.4	8.9 ± 1.4	0.11	<0.001	0.004
Vessel density (mm/mm^2)						
Complete	18.0 ± 1.9	14.3 ± 3.6	14.3 ± 3.6	0.009	<0.001	0.65
Central	12.0 ± 2.8	7.9 ± 4.3	10.8 ± 3.6	<0.001	<0.001	0.09
Inner ring	18.1 ± 2.4	14.4 ± 3.9	16.4 ± 2.4	0.001	<0.001	0.07
Outer ring	17.8 ± 1.5	14.5 ± 16.7	116.7 ± 6.4	0.01	<0.001	0.27
Perfusion density (%)						
Complete	42.6 ± 3.2	35.2 ± 9.7	39.2 ± 6.5	0.005	<0.001	0.06
Central	25.7 ± 6.4	17.8 ± 10.0	24.4 ± 8.3	0.001	<0.001	0.49
Inner ring	42.4 ± 4.0	33.9 ± 11.2	38.5 ± 7.3	0.004	<0.001	0.07
Outer ring	43.7 ± 3.2	36.6 ± 9.2	38.7 ± 6.7	0.17	<0.001	0.003
SD-OCT parameters						
CMT (μm)	284 ± 24	284 ± 31	283 ± 26	0.59	0.84	0.95
SFCT (μm)	248 ± 48	210 ± 74	205 ± 72	0.22	0.009	0.003
STRV diameter (μm)	124 ± 22	136 ± 18	122 ± 15	<0.001	0.008	0.65
STRA diameter (μm)	90 ± 15	98 ± 17	94 ± 13	0.32	0.04	0.21

ADHF, acute decompensated heart failure; BCVA, best corrected visual acuity; CG, control group; CMT, central macular thickness; E1, first exam; E2, second exam; IOP, intraocular pressure; OCT-A, optical coherence tomography angiography; SD-OCT, spectral domain-optical coherence tomography; SFCT, subfoveal choroidal thickness; STRA, superior temporal retinal artery; STRV, superior temporal retinal vein.

Similar to the vessel density findings, after recompensation, there was no significant difference in perfusion density compared to the control group (39.2 ± 6.5 vs. 42.6 ± 3.2%, $p = 0.06$) (*Figure 3C*).

Figure 3A shows a control subject with a vessel density of 19.9 mm/mm^2 and a perfusion density of 48.4% compared to a patient with ADHF with both examinations at admission and discharge. At discharge, a significant increase in the total vessel and perfusion density was observed (vessel density: 19.1 mm/mm^2, perfusion density: 47.6%) compared to the initial examination on admission (vessel density: 17.5 mm/mm^2, perfusion density: 44.8%).

Macular and choroidal thickness and retinal vessel diameters

At admission, the mean central macular thickness measured 284 ± 31 μm, which was comparable to the thickness recorded at discharge (283 ± 26 μm, $p = 0.59$) (*Table 2*). No significant alterations in central macular thickness were observed between the control group and both examinations at admission and discharge. There were no significant changes in the mean subfoveal choroidal thickness between admission and after recompensation (210 ± 74 μm vs. 205 ± 72 μm, $p = 0.22$), but it was significantly higher in the control group compared to both exanimations at admission and discharge (248 ± 48 vs. 210 ± 74 μm, $p = 0.009$ and 248 ± 48 vs. 205 ± 72 μm, $p = 0.003$, respectively) (*Table 2*).

The mean diameter of the superior temporal retinal vein measured 136 ± 19 μm at admission and exhibited a significant decrease to 122 ± 15 μm at discharge ($p < 0.001$). Remarkably, after recompensation, no significant difference in the diameter of the superior retinal vein was observed compared to the control group (122 ± 15 μm vs. 124 ± 22 μm, $p = 0.65$) (*Figure 4A*).

The diameter of the superior temporal retinal artery was found to be larger compared to the control group (98 ± 17 vs. 90 ± 15 μm, $p = 0.04$). There was no change in the diameter of the superior temporal retinal artery before and after recompensation (98 ± 17 vs. 94 ± 13 μm, $p = 0.32$) (*Figure 4B*).

Discussion

This study revealed a notable decrease in intraocular pressure after recompensation, as well as a significant reduction in both macular vessel density and perfusion density during acute decompensation compared with the control group, followed by a significant increase after recompensation (*Table 3*). Additionally, the diameter of the superior temporal vein of the retina showed a significant reduction after recompensation (*Graphical Abstract*).

Several population-based studies have established a link between retinal microvascular signs and the incidence of HF.[16,17] However, the role of retinal imaging in individuals with confirmed HF has not been thoroughly investigated. It has been shown that abnormal values of functional intrinsic diameter of arterioles and venules were notably higher in HF patients compared to those with cardiovascular comorbidities and healthy individuals, possibly reflecting sub-clinical congestion.[9]

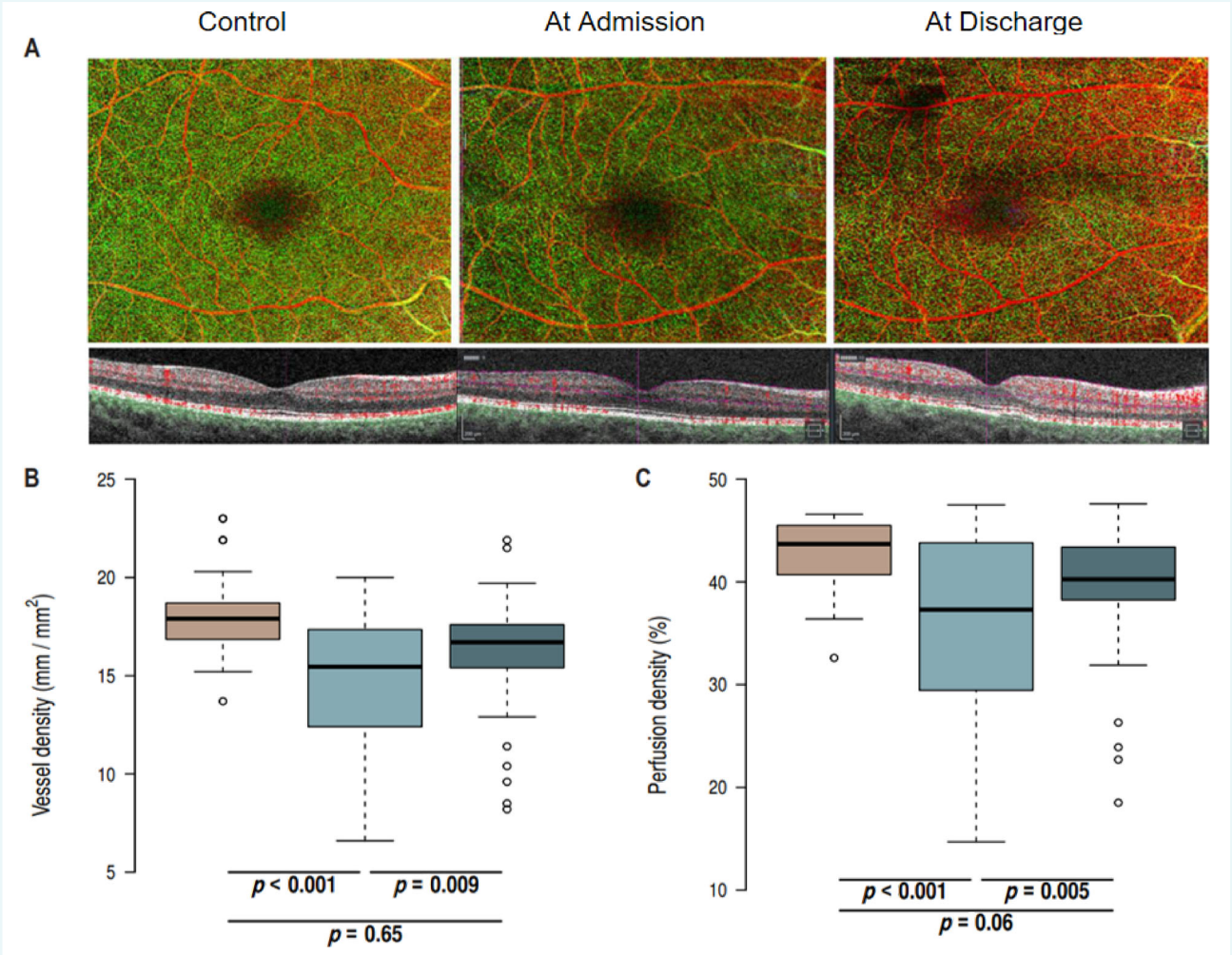


Figure 3 (*A*) Depth-encoded optical coherence tomography angiography (6 × 6 mm) showing a subject from the control group with a vessel density of 19.9 mm/mm^2 and a perfusion density of 48.4% compared to a patient with acute decompensated heart failure showing the increase in vessel density and perfusion density in the same eye between the examinations on admission (vessels density: 17.5 mm/mm^2, perfusion density: 44.8%) and at discharge ([*B*, *C*] vessels density: 19.1 mm/mm^2, perfusion density: 47.6%). Red represents the superficial retinal layer. Green represents the deep retinal layer. Yellow represents overlying regions. The lower pictures show B-scans with the flow signal. The images are taken from an AngioPlex™ device (Cirrus HD-OCT model 5000; Carl Zeiss Meditec AG).

Optical coherence tomography angiography offers several advantages over simple bedside eye examinations: it is a fast, non-invasive procedure that provides accurate and quantitative structural blood flow parameters, detects subclinical micro changes, and simultaneously visualizes both the retinal and choroidal vasculature.[11,18] However, it also has disadvantages, including a limited field of view, inability to detect fluid leakage, a higher risk of artefacts, and difficulty in performing the procedure in patients with poor fixation. Some recent studies have attempted to detect altered ocular perfusion in patients with chronic HF.[16] These demonstrated a reduction in vessel density and perfusion density compared to healthy controls, even in children.[19,20] These findings led to the question whether such retinal microvascular changes can also be detected in the acute stage of HF.

In this analysis, OCT-A was used to evaluate alterations in retinal vasculature in adult patients with ADHF. Several microvascular changes in the eye attributed to systemic congestion were observed. Vessel and perfusion density were reduced during episodes of acute decompensation, followed by noteworthy improvements after recompensation. This finding is supported by the significant decline of NT-proBNP and IVC diameter. A plausible explanation could be the increase in central venous pressure during acute decompensation, leading to a subsequent reduction in the net pressure gradient across the retina with subsequent hypoperfusion and reduced vascular density.[21–23] However, the improvement observed after recompensation does not indicate complete normalization. It primarily affects certain parameters such as vessel density and perfusion density, while other parameters like visual acuity and choroidal thickness remain

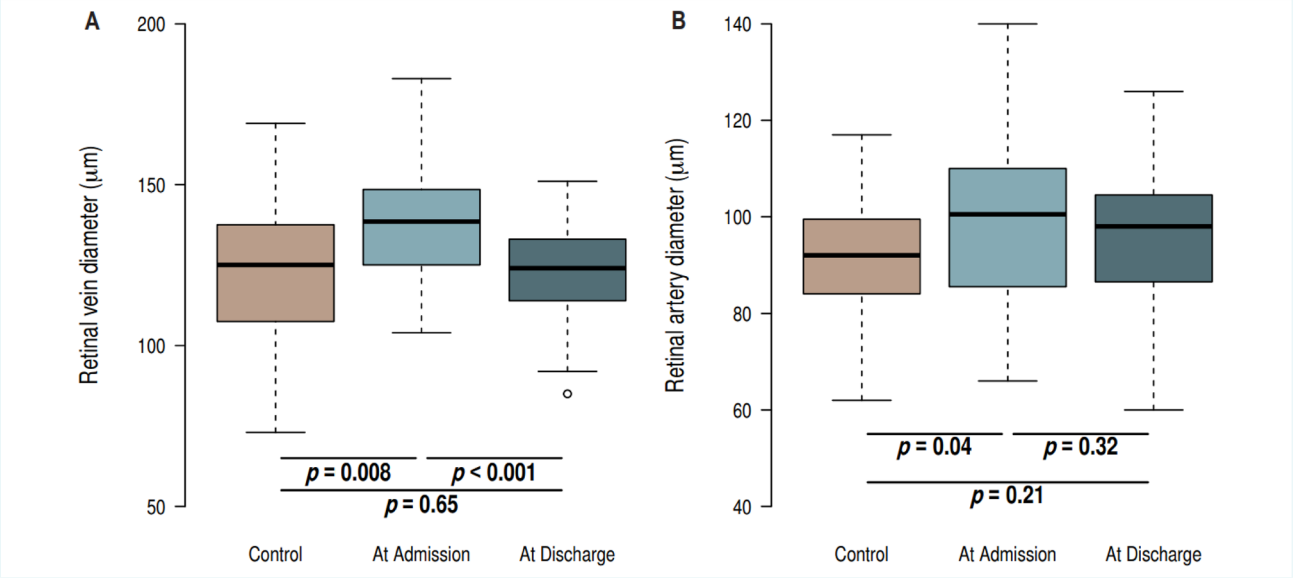


Figure 4 Mean retinal vessel diameter at admission and at discharge compared to that of the control group.

Table 3 Changes in ocular parameters in patients with acute decompensated heart failure

Ocular parameter	Acute decompensation	After recompensation
Visual acuity	↓↓	↓↓
Subfoveal choroidal thickness	↓↓	↓↓
Vessel and perfusion density	↓↓	↔
Retinal vein diameter	↑↑	↔
Intraocular pressure	↔	↓↓
Central macular thickness	↔	↔

Pathological findings (red), within normal limits (green).
Compared to the control group: ↓↓ reduced, ↑↑ increased, ↔ comparable.

impaired compared to the control group. This suggests that a treatment period of only 4–5 days is insufficient to fully reverse these changes. It also highlights the need for further studies with longer observation periods to document long-term changes across all parameters.

In our study, the diameter of the retinal artery was significantly larger than in the control group and decreased after recompensation. A possible explanation could be that acute cardiac decompensation often leads to elevated blood pressure, which can increase the pressure in retinal arteries, potentially causing damage, increases in diameter, or structural changes. Additionally, fluid retention can lead to vascular congestion, causing the retinal arteries to become engorged and tortuous.

Although the mean intraocular pressure upon admission was similar to that of the control group, it notably decreased upon discharge. This short-term alteration is likely due to acute fluctuations in hydrostatic pressure within the systemic venous system, impacting the circulation of ocular and choroidal veins and obstructing transscleral drainage of intraocular fluid during decompensation. These immediate changes following recompensation underscore the dynamic nature of such physiological processes.

Some studies have suggested that patients with chronic HF experience more severe functional visual impairment compared to healthy individuals.[24] Similarly, our study revealed significantly poorer visual acuity in patients with ADHF compared to controls. However, this visual acuity did not change between the decompensation and subsequent recompensation phases. This indicates that the observable improvement after recompensation in our study did not signify complete normalization. The improvements were primarily in anatomical parameters, such as retinal vein diameter, vessel density, and perfusion density, rather than in functional parameters like visual acuity. This discrepancy may be due to acute microvascular alterations leading to impaired local tissue perfusion, which could be associated with the development of irreversible organ failure.[25,26]

Acute microvascular changes have been observed in patients with ADHF.[27] Similar findings have been reported in other cardiac diseases. For instance, den Uil *et al.*[28] discovered impaired microcirculation by examining sublingual capillary density in patients with cardiogenic shock. They questioned whether improving vessel density in these patients would lead to better survival and organ function. This indicates that further studies with longer observation periods are necessary to determine the long-term changes in functional parameters, such as visual acuity.

Similar to other peripheral organs, the choroid, primarily composed of terminal branches of blood vessels, may experience hypoperfusion when LVEF and systemic arterial pressure are decreased. This hypoperfusion can result in a reduction in choroidal vessel density, which correlates with the observed decrease in subfoveal choroidal thickness in this study. Comparable choroidal changes have been reported in other clinical studies, albeit in patients with chronic HF.[29,30]

Systemic congestion resulting from ADHF leads to acute chorioretinal changes. These acute alterations may potentially influence the subsequent chorioretinal remodelling that occurs over the years. This study could provide valuable evidence supporting the use of OCT-A in assessing overall microperfusion and haemodynamic status, potentially optimizing therapy to improve prognosis in patients with ADHF. The systemic congestion caused by ADHF may influence subsequent chorioretinal remodelling over the years, becoming a risk factor for various eye diseases, such as pachychoroid disease. This opens the door to further investigations into the potential cardio-ocular syndrome and the ramifications of congestion on the eye, including possible long-term consequences.

The strength of this work lies in the utilization of a non-invasive test that offers a repeatable and quantitative assessment of abnormalities in retinal vasculature. This was applied to a homogeneous group of HF patients who were systematically examined. All patients enrolled in our study underwent transthoracic echocardiography, chest x-ray, and blood tests. This comprehensive approach allowed us to evaluate congestion both at admission and discharge and assess the correlation between ocular changes, cardiac imaging and biomarkers. Limitations include a relative small patient population, underscoring the necessity for further investigations involving larger cohorts. Another important aspect of our study is that most of our patients were multimorbid. Conditions such as hypertension and diabetes are known to cause retinal changes that are unlikely to disappear after a few days of treatment. To address this, we excluded all eyes with visible vitreoretinal diseases, such as hypertensive or diabetic retinopathies, to avoid any potential overlap. However, we must consider that some of the observed acute alterations, particularly in functional changes and vascular diameters, could be attributed to these associated systemic diseases. Additionally, the confounding effects of concomitant therapies initiated or discontinued during hospitalization should not be overlooked.

Conclusion

Acute decompensated HF is associated with a subsequent change in retinal microvasculature. Utilizing OCT-A to assess retinal perfusion may offer valuable insights for overall microperfusion and haemodynamic status of patients with ADHF. Additional investigations are warranted examining cardio-ocular syndrome and the ramifications of congestion on the eye, including possible long-term consequences.

Supplementary Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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