Efficacy of conventional and hyperbaric oxygen therapy on central retinal artery occlusion: What is the critical time?

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ABSTRACT

Purpose: To investigate the clinical results and efficacy of conventional medical therapy and hyperbaric oxygen therapy (HBOT) in patients with central retinal occlusion (CRAO). Methods: This study employed a single-center, non-randomized, retrospective case-control design, involving 29 patients with non-arteritic CRAO. Massage, topical and systemic oral hypotensive treatments, and acetylsalicylic acid (conventional therapy) were applied to all patients. Seventeen cases also received 20 sessions of HBOT, a protocol chosen based on previous studies and clinical experience. Clinical outcomes and complications of the cases were evaluated before and after treatment. Results: In Group 1 (HBOT group), one or more visual improvements were observed in 12 (70.6%) of 17 patients. In group 2 (non-HBOT group), one-line visual improvement was detected in 2 (16%) of 12 patients. The mean improvement increased from 2.3±0.7 log MAR to 1.6±0.7 (p=0.001) in 12 (70.5%) patients if HBOT was initiated within 48 hours. When patients underwent HBOT within 24 hours (≤ 16 hours), the visual acuity of 58.8% (10 patients) showed a mean improvement of log MAR from 2.6 ± 0.4 to 1.8 ± 0.5 log MAR (p = 0.0001) in Group 1. Analysis of the ROC curve demonstrated that HBOT was correlated with improvement of visual acuity (Log MAR), with 64.7 % sensitivity and 100 % specificity Conclusion: Although our study yields promising results, it is essential to acknowledge that no medical treatment modalities are currently based on conclusive evidence. HBOT shows potential as supportive care until retinal reperfusion. The results of our study suggest that devastating visual loss can be prevented if HBOT starts as early as possible, within 16 hours. However, further randomized clinical trials are required in large series to understand and fully harness the potential of HBOT, highlighting the ongoing research in the field.

Keyword: Fundus fluorescein angiography, hyperbaric oxygen, retinal artery occlusion, retinal ischemia, visual acuity

INTRODUCTION

Central Retinal Artery Occlusion (CRAO) has been known as a clinical entity since 1859 and was first described as CRAO due to embolism by von Graefe.[1] Its incidence is 1– 15 per 100,000 people.[2] CRAO causes a stroke and infarction of the inner retinal layers. The ganglion cells are critically dependent on the oxygen supplement of the central retinal artery.[3,4] If the retinal ischemia time exceeds 4–6.5 hours, all therapeutic options might be ineffective due to the limited ischemic tolerance.[5] Retinal oxygen deprivation in animal models causes irreversible tissue damage after 97 minutes, and occlusions lasting more than 100 minutes cause. It is not precisely known when irreversible retinal damage may occur in humans compared to anoxic animal models.

CRAO typically presents as acute, catastrophic, permanent visual loss in one eye, about 80% of the time, with a visual acuity of 20/400 or lower, an afferent pupillary defect, a classic retinal cherry red spot from opacification of the infarcted ganglion cell layer surrounding the fovea, and

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sometimes a visible CRA embolus or other retinal arterial emboli.[6,7]

The treatment of CRAO includes reducing intraocular pressure (IOP) via pressure-lowering medication or anterior chamber paracentesis, as well as sublingual isosorbide dinitrate and carbon dioxide or carbogen inhalation. Additionally, intra-arterial fibrinolysis, surgical embolectomy, or neodymium:yttrium–aluminum–garnet laser hemolysis may be employed.[8-11] Conservative treatments can be used as monotherapy or combination therapy. The efficacy and visual improvement rates of these therapies are 6-49% and 15-21%, respectively. [12]

The retina receives oxygen from its arterial supply, and the outer retina and choroid receive oxygen via passive oxygen diffusion. [13] Half of the inner retinal oxygen is derived from the outer retinal-choroidal circulation, while the application of hyperbaric oxygenation increases to 97%. [14] The occlusion can be bypassed to oxygenate the ischemic retina until spontaneous reperfusion occurs. It is unknown which patients may benefit from this therapy and when the critical time is.

Our study aims to determine the critical time from the onset of CRAO to inner retinal infarction, in order to avoid catastrophic visual loss, and to compare conventional treatment with hyperbaric oxygen therapy (HBOT).

MATERIALS AND METHODS

This cross-sectional, retrospective observational case study was conducted with 29 participants recruited from patients at Izmir Katip Çelebi University, the Affiliated Atatürk Training, and the Research Hospital's Eye Clinics from May 2016 to February 2024. The patients were selected based on their diagnosis and the reliability of the reported time of symptom onset. The study was approved by the Institutional Ethics Committee of Izmir Katip Çelebi University (approval number 22/0472) and conducted in accordance with the principles outlined in the Declaration of Helsinki. Informed consent was obtained from all participants. The study included 29 Caucasian patients with non-arteritic CRAO (From the first patient to patient 17 were included in Group 1, and the others were included in Group 2). All patients received conventional treatment, with refractive errors ranging from +3.0 to -3.0 diopters and intraocular pressures (IOPs) lower than 21 mmHg. Seventeen of the 29 patients received HBOT (Group 1), while the others declined it (Group 2). One patient was excluded from our study due to the detection of a patent cilioretinal artery.

We excluded arteritic CRAO, patent cilioretinal artery, retinal vein occlusion, active bleeding, recent stroke or hemorrhage, Susac syndrome, degenerative central macular disease, uveitis, glaucoma, high myopia, and high hypermetropia, as well as a history of intravitreal injection, scleral buckling, or vitrectomy.

All participants underwent an ophthalmologic examination that included best-corrected visual acuity (BCVA), slit-lamp biomicroscopy, Goldmann applanation tonometry, and fundus examination performed after the pupil was dilated with 1% tropicamide (Alcon®, Denmark). All ophthalmic examinations were completed by the same specialist. BCVA was examined using the international standard Snellen visual acuity chart and converted to 'Logarithm of the Minimum Angle of Resolution' (LogMAR) visual acuity records for statistical analysis.

Blood parameters, including complete blood count, erythrocyte sedimentation rate, C-reactive protein, clinical chemistry (glucose, sodium, potassium, creatinine, uric acid, total cholesterol, triglycerides, alanine aminotransferase, aspartate aminotransferase, gamma-glutamyl transferase, total bilirubin, total protein, and homocysteine) were recorded.

All patients with a reliably reported time of symptom onset within the past 48 hours were included in the study and also performed fundus fluorescein angiography (FFA) (Zeiss Pro NM Retinal Camera, Carl Zeiss Meditec AG, 07740 Jena Germany) at their primary visit within 48 hours after ischemia onset was included in the further evaluation. Patients with reperfused CRAOs, arteritic CRAO, a cilioretinal artery, or retinal pathologies other than CRAO in either the affected eye/or the fellow eye (e.g., epiretinal gliosis, macular degeneration, etc.) and/or reporting about reduced visual acuity in either eye before CRAO were excluded.

STATISTICAL ANALYSIS

Statistical analysis was performed using the software SPSS v. 30 (SPSS Inc., IBM Corp, Chicago, Illinois, USA).

Descriptive statistics were given as units (n), percentage (%), mean ± standard deviation, median, and interquartile distance values. The normal distribution of the data of numerical variables was evaluated with the Shapiro-Wilk normality test. The homogeneity of variance of the groups was analyzed using the Levene test. Comparisons between groups were made with independent samples, a t-test for age variable, and a Fisher exact test for gender and eye. Comparisons between preoperative and postoperative groups for BCVA were made with the Mann-Whitney U test, and within-group comparisons for group 1 were made with the Wilcoxon test. Two-way repeated measures analysis of variance (ANOVA) was used for inter-group and intra-group comparisons for preoperative and postoperative LogMAR values of the groups. Bonferroni correction was applied to comparisons in two-way ANOVA. Spearman's correlation analysis was used to compare numerical variables with each other. $p<0.05$ value was considered statistically significant. The performance of pre-HBOT and post-HBOT in predicting the patient group was evaluated using the receiver operating characteristic (ROC) curve analysis. A $P<0.05$ value was considered statistically significant.

RESULTS

This study retrospectively evaluated all available FFA patients with CRAO who presented at a single tertiary care facility between May 2016 and February 2024. Twenty-nine patients (mean age 64.4; range 26-89) with acute CRAO, known time of symptom onset (≤48 hr), and available optical coherence tomography (OCT) from their primary presentation (≤48 hr) (Table 1). In Group 1, HBOT (daily 2-hour sessions at 253 kPa for 20 days) was performed in 17 patients (from 1 to 17). In Group 2, 12 patients had no HBOT. The male-to-female ratio was 5:12 in group 1 and 4:8 in group 2. The mean follow-up periods were 16 ± 9.3 months in group 1 and 16.5 ± 8.0 in group 2. Hyperhomocysteinemia was detected in one case (a 26-year-old) in group 1. The baseline characteristics of the patients and statistical values of the groups are shown in Tables 1 and 2.

When patients underwent HBOT within 24 hours after the onset of symptoms (between the onset of symptoms and admission time), the visual acuity of 10 patients (58.8%) showed a mean improvement of log MAR from 2.6±0.4 to 1.8±0.5 log MAR ($p = 0.0001$) in Group 1. The mean improvement increased from 2.3±0.7 log MAR to 1.6±0.7 ($p=0.001$) in 12 (70.5%) patients in group 1 if HBOT was initiated within 48 hours.

Ten of 17 (58.8%) HBOT patients had one or more line improvements in BCVA of group 1, whereas 2 of 12 (16.6%) patients with non-HBOT had one line improvement in BCVA within 24 hours in group 2. Figures 1 and 2 illustrate the differences between BCVA and time presentation in groups 1 and 2. Analysis of the receiver operating characteristic (ROC) curve showed that HBOT was correlated with an improvement in visual acuity (Log MAR), with 64.7 % sensitivity and 100 % specificity. Table 3 and Figure 3 present the ROC curve analysis for Pre-HBOT and Post-HBOT in group 2.

Pre-HBOT and post-HBOT color fundus photography and FFA images of patients were given in Figures 4 and 5.

DISCUSSION

Risk factors for CRAO include age over 60, male gender predominance, emboli originating from the heart or carotid arteries, hypercholesterolemia, arterial hypertension, carotid artery stenosis, diabetes mellitus, transient ischemic attacks (TIAs) or cerebral vascular accidents, and smoking tobacco. In younger patients, proatherogenic states, such as hyperhomocysteinemia, factor V Leiden, protein C and S deficiencies, anti-thrombin deficiencies, anti-phospholipid antibodies, prothrombin gene mutations, sickle cell disease, and migraine due to vasospasm, as well as paraneoplastic syndromes, may all contribute to non-arteritic CRAO. (4,15). In our study, the mean age of the group with HBOT was 65.4±15.2, and it included female predominance (70.6%), arterial hypertension (64.7%), diabetes mellitus (37.4%), coronary heart disease (5.8%), and hyperhomocysteinemia (3.4 %)

When the elapsed time (from the onset of visual loss to the beginning of HBOT) was 24 hours or less, BCVA could have improved by one line or more in 58.8% of the patients. If the elapsed time had been lower than 16 hours, BCVA could have improved by two lines or more in 41,1% of the patients treated with HBOT. In group 2, 83.3% of patients experienced no changes in BCVA, and 16.6% showed a spontaneous improvement of one line in BCVA after conventional therapy.

Table 1. Baseline characteristics of the patients with central retinal artery occlusion (CRAO).

Patients	Sex	Age	Systemic Diseases	Eye	Elapsed time (hours)	HBOT	BCVA at Presentation	BCVA in the first month
1	M	65	HT	R	8	+	2.3	2.3
2	F	26	hyperhomocystenemia	R	4	+	3	1.8
3	F	79		R	5	+	3	1.8
4	F	84	HT	L	20	+	3	3
5	F	73	HT, CVD	R	3	+	1.8	1.7
6	F	75	HT, DM	R	48	+	2.3	2.3
7	M	70	Aritmia	R	3	+	2.3	1.8
8	F	64	HT, DM	R	16	+	2.3	1.7
9	F	83	HT	L	24	+	3	2.3
10	F	45		R	24	+	2.3	2.3
11	F	79	HT, DM	R	12	+	2.3	1.8
12	F	71	HT, DM	L	4	+	2.3	1.5
13	F	68		R	48	+	2.3	2.3
14	F	61	HT, DM	L	48	+	2.3	2.3
15	M	49	HT	R	48	+	1.8	1.7
16	M	51	CVD	L	1	+	1.7	0.8
17	M	70	HT, DM	L	48	+	2.3	2.3
18	M	51		L	2	-	2.3	2.3
19	F	70	DM	R	18	-	2.3	2.3
20	F	89	DM	L	10	-	3	3
21	F	73	HT, DM	R	24	-	3	2.3
22	M	58	CVD	R	48	-	3	3
23	F	53	HT	R	15	-	2.3	2.3
24	F	67	HT	L	24	-	2.3	2.3
25	F	48		R	48	-	3	2.3
26	M	72	HT, DM	R	12	-	3	2.3
27	M	81	HT	R	36	-	3	3
28	F	49	DM	L	10	-	2.3	2.7
29	F	63		R	24	-	2.3	2.3

M: male, F: female, R: right, L: left,, HBOT: hyperbaric oxygen therapy, BCVA: best corrected visual acuity (LogMAR), Group 1: patients' number 1-17, Group 2: patients number 18-29, HT: hypertension, DM: diabetes mellitus, CVD: cardiovascular disease

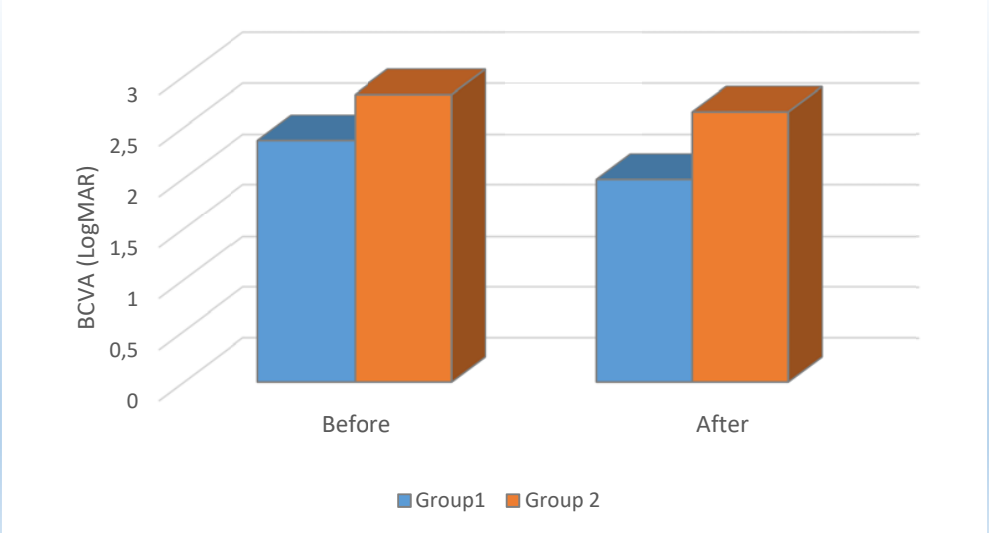

Figure 1. *Changes of best-corrected visual acuity as* ***'Logarithm of the Minimum Angle of Resolution' (LogMAR)*** *before and after treatment in groups (Group 1: HBOT, Group 2: non-HBOT).*

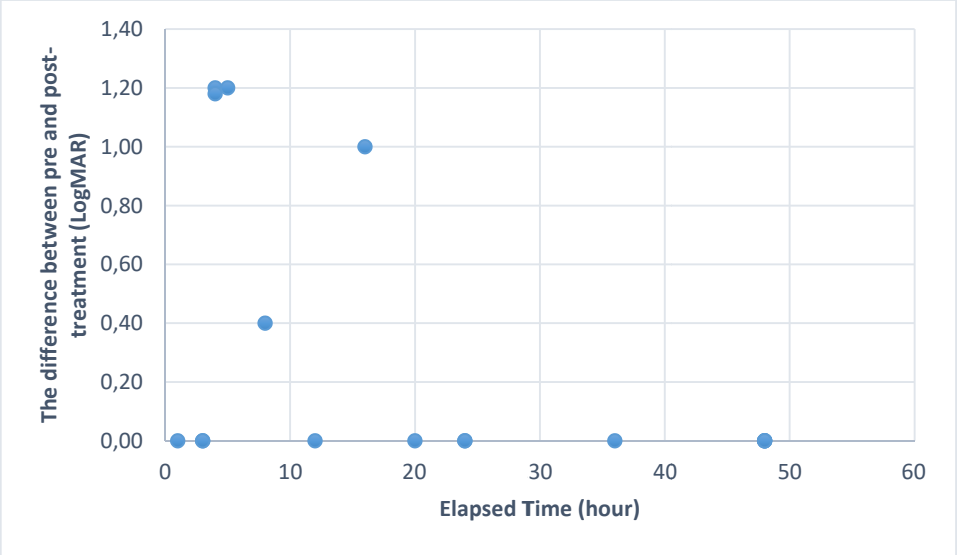

Figure 2. *Distribution of best-corrected visual acuity as* ***'Logarithm of the Minimum Angle of Resolution' (Log MAR)*** *according to elapsed time (symptom duration before treatment) in patients with HBOT.*

Table 2. Descriptive and comparative statistical values in groups.

	Group 1 (HBOT) *n*=17	**Group 2 (non-HBOT)** *n*=12	*p*
Sex, *n* (%)			
Female	12 (70.6)	7 (58.3)	*0.694*‡
Male	5 (29.4)	5 (41.7)	
Age (year)	65.4±15.2	61.9±11.3	*0.500*&
Eye, *n* (%)			
Left	5 (29.4)	5 (41.7)	*0.694*‡
Right	12 (70.6)	7 (58.3)	
Follow-up time (day)	12 (6-34)	15.5 (7-36)	*0.647*&
Elapsed time (hours)	16 (1-48)	23 (10-48)	*0.245*&
BCVA (LogMAR)			
Pre-treatment	2.48±0.66	2.68±0.35	*0.331*†
Post-treatment	1.94±0.76	2.45±0,28	*0.037*†
Difference	0.53±0.48	0.23±0.34	*0.074*†
p	*<0.001*ᵗ	*0.070*ᵗ	

HBOT: hyperbaric oxygen therapy, BCVA: best corrected visual acuity, **Data* are given as number (column percent), median (interquartile range) or mean standard deviation, ‡: Fisher exact test, &: Independent samples *t* test.ᵝ Data are given as follows: † Two-way repeated measures analysis results (between groups). ᵗ: Two-way repeated measures analysis results (within groups).

Table 3: Receiver operating characteristic (ROC) curve analysis for Pre-HBOT and Post-HBOT.

	AUC (95.0% *C.I.*)	*p*	Cutoff value	Sensitivity (95.0% *C.I.*)	Specificity (95.0% *C.I.*)	PPV (95.0% *C.I.*)	NPV (95.0% *C.I.*)
Pre HBOT LogMAR	0.603 (0.405-0.779)	0.353	≤2.7	76.5 (50.1-93.2)	50.0 (21.1-78.9)	68.4 (53.7-80.2)	60.0 (34.9-80.7)
PostHBOT LogMAR	0.750 (0.555-0.891)	0.006	≤1.8	58.8 (32.9-81.6)	100.0 (73.5-100.0)	100.0 (100.0-100.0)	63.2 (49.3-75.2)

AUC: Area under the curve, *C.I.*: Confidence interval, *PPV*: Positive predictive value, *NPV*: Negative predictive value

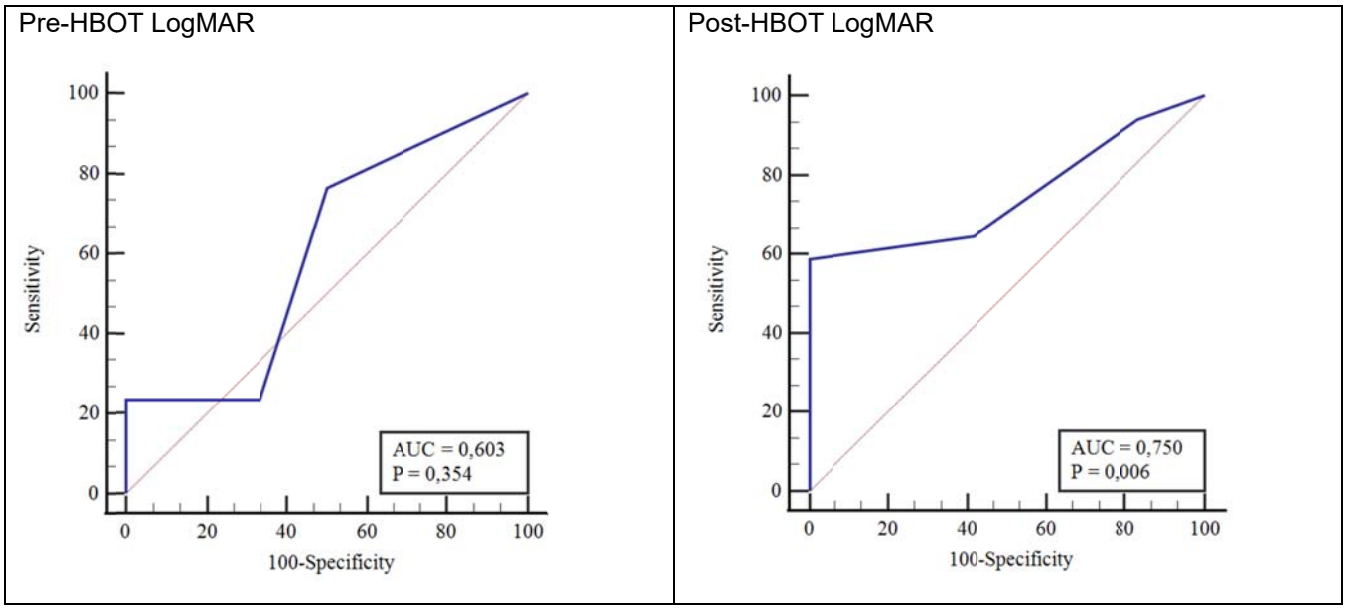

Figure 3. *Pre-HBOT and post-HBOT* ***receiver operating characteristic (ROC) curve analysis graphics.***

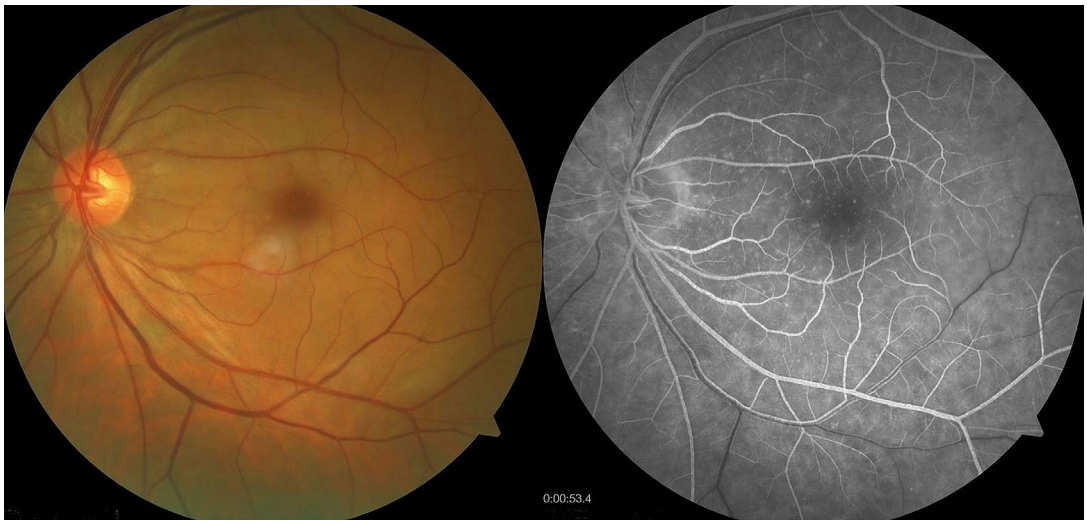

Figure 4: *Color fundus photo and middle phase of* ***fundus fluorescein angiography*** *(FFA) photo at preterm of HBOT* ***(Patient 8th of Group 1).***

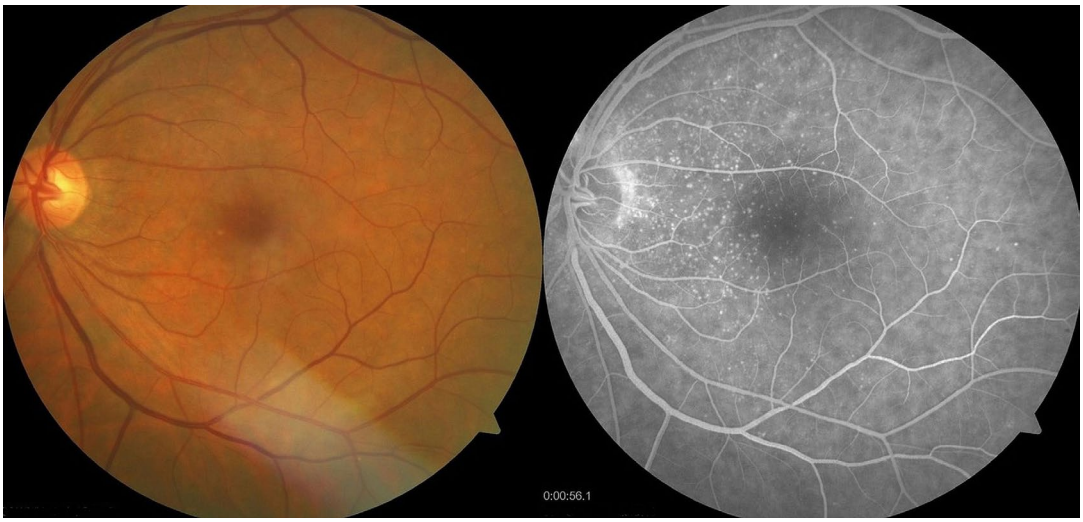

Figure 5: *Color fundus photo and middle phase of FFA photo at post-term of HBOT* ***(Patient 8th of Group 1).***

Hayreh reported that 37% of patients with CRAO experienced spontaneous improvement in their visual acuity (VA). [16] In our study, conventional treatment resulted in visual improvement in 20% of patients, but this improvement was insignificant.

Wu et al. reported in the meta-analysis study that a significant difference was observed between the normobaric and hyperbaric oxygen groups, demonstrating that oxygen pressure played an essential role in visual improvement. [17]

Several case series support that hyperbaric oxygen can improve outcomes following CRAO. [18-23] Aisenbrey et al. reported a mean increase in visual acuity of 2 lines in eight patients treated with HBOT.[24] Beiran et al. found that over 80% of patients in their series reported subjective improvement in vision with hyperbaric oxygen therapy (HBOT) compared to less than 30% in the control group.[18,19] In a series of 21 patients, 19 noted subjective improvement of vision, confirmed in 13 patients by visual acuity testing.[21] Cope et al. pooled data from their case series of 11 patients with data from two other case series of HBOT, giving a combined total of 51 patients. They found that more than half of the patients experienced VA improvement of greater than two lines with HBOT.[22] Menzel-Severing et al. compared the visual outcome in 51 HBO-treated patients with that in a control group of 29 patients. They found an improvement in three lines of vision in the HBOT group, compared to only one line in the control group.[23]

Chiabo et al. found that 48.4% of patients significantly improved BCVA, a decrease of ≥0.3 log MAR after one month of treatment.[24]

John Blegen et al. emphasized the necessity for close monitoring of this patient with diabetes treated acutely with HBOT for CRAO in the case series study. Two of the three patients with diabetes subsequently went on to develop ocular neovascularization within 1 month of presentation.[25]

St. Peter et al. stated that patients who underwent HBOT earlier than 24 hours of symptom onset experienced an average visual acuity improvement of 0.5 log MAR (p=0.01) [26]. Hsieh et al. presented that after HBOT, the patient's BCVA improved from 20/200 to 20/20 in the affected eye. HBOT may be a feasible and effective treatment for combined branch retinal artery occlusion (BRAO) and branch retinal vein occlusion (BRVO).[27]

While these studies vary in selection criteria and treatment algorithms, the vast majority recruited only patients who presented to them within 24 hours of symptom onset. These studies indicate that early HBOT may improve outcomes following CRAO.

Retinal infarction typically occurs within 12–15 minutes of complete CRAO.[28] It explains why therapeutic approaches for CRAO are often ineffective. Many CRAOs are incomplete and may benefit from therapy after longer intervals [16].

The class of recommendation for HBOT by the American College of Cardiology/American Heart Association (ACC/AHA) clinical practice guidelines is IIb, indicating that it is not unreasonable to perform procedures or administer treatment.[29] The Undersea and Hyperbaric Medicine Society (UHMS) states that patients presenting CRAO within 24 hours of symptom onset should be considered for HBOT.[30] In normobaric conditions, choroidal circulation supplies 60% of the oxygen the retina needs, which increases to 100% under hyperbaric conditions. HBOT also decreases edema and preserves compromised tissue adjacent to an ischemic area. [31,32]

In conclusion, timely treatment initiation is crucial to prevent permanent visual loss. Patients with CRAO should be urgently transferred to a HBOT clinic. A close connection between ophthalmologists and cardiologists is recommended.

The main factors determining visual prognosis are the patient's initial visual acuity and the elapsed time (specifically within 16 hours), which appears to be the critical period. Starting HBOT as early as possible can lead to a further increase in visual acuity. Randomized trials are necessary for more extensive series to demonstrate the proven effect of HBOT and its critical time.

STATEMENT ON COMPLIANCE WİTH ETHICAL STANDARDS

Author contributions

Erdinc Aydin: Conceptualization, Methodology, Writing – review & editing, Project administration. *Seda Gurakar Ozcift:* Resources, Validation.

Levent Kazanci: Resources. *Ferhan Elmali:* Data curation, Statistical calculations.

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Declarations

Conflict of interest

The authors declare no competing interests.

Ethical approval

The study was approved by the Institutional Ethics Committee of Izmir Katip Çelebi University (approval number 22/0472) and was conducted in accordance with the Helsinki Declaration.

Consent to participate

Informed consent was obtained from all individual participants included in the study. This article does not contain any studies with animals performed by any of the authors.

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None

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