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Short-term Outcomes of Laser Photocoagulation for Exudative Retinal Arterial Macroaneurysm With Versus Without Hemorrhage: A Retrospective Comparative Case Series Short title: Laser outcomes in exudative retinal macroaneurysm

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Abstract

Purpose

To describe short-term visual and anatomical changes after laser photocoagulation for exudative retinal arterial macroaneurysm (RAM) and to compare outcomes according to the presence or absence of RAM-related hemorrhage.

Methods

This retrospective comparative case series included 12 patients (12 eyes) with exudative RAM treated with a single session of laser photocoagulation. Seven eyes had RAM-related hemorrhage and five did not. In eyes with hemorrhage, laser treatment was deferred until the accumulated blood had spontaneously resorbed sufficiently to permit clear visualization and treatment of the lesion. Best-corrected visual acuity (BCVA), central macular thickness (CMT), aneurysm thickness, and retinal hard exudate area were evaluated immediately before laser treatment and at 1 week, 1 month, and 2 months. Counting-fingers and hand-movements visual acuities were assigned logMAR values of 1.85 and 2.28, respectively. Longitudinal and between-group analyses used nonparametric tests with Holm correction for multiple comparisons.

Results

Across all eyes, BCVA improved and CMT, aneurysm thickness, and hard exudate area decreased at every follow-up compared with baseline (Holm-adjusted $P <= 0.004$). Baseline CMT was strongly inversely correlated with fovea-macroaneurysm distance (Spearman $r_s = -0.963$, permutation $P < 0.001$). Reductions in CMT and aneurysm thickness were greater in the nonhemorrhagic group than in the hemorrhagic group at all follow-up visits (Holm-adjusted $P <= 0.010$). Between-group differences in BCVA improvement did not remain significant after multiplicity correction (adjusted $P = 0.083$), and no between-group difference in hard exudate area reduction was detected (adjusted $P = 0.557$). No follow-up correlation between fovea-macroaneurysm distance and CMT reduction remained significant after correction for exploratory multiple testing.

Conclusions

Laser photocoagulation was associated with short-term visual and anatomical improvement in this small series of exudative RAM. Hemorrhage status was associated with the magnitude of CMT and aneurysm-thickness reduction, while pretreatment fovea-macroaneurysm distance was associated with baseline macular thickening. These exploratory findings require confirmation in larger controlled studies.

1. Introduction

Retinal arterial macroaneurysm (RAM) is an acquired focal dilatation of a retinal artery, and Robertson introduced the term in 1973 [1]. The Beijing Eye Study found RAM in approximately 1 of 4500 adult Chinese participants [2]. The Central India Eye and Medical Study reported a higher population frequency of approximately 1 in 1500 participants aged 30 years or older [3]. Clinical series indicate that RAM predominantly affects older adults, particularly women [4]. Most lesions arise along a temporal retinal artery within the first three arterial bifurcations [5]. Systemic hypertension and retinal arteriolar sclerosis are common associations [6].

Clinical presentation is heterogeneous, and RAM may be quiescent, exudative, hemorrhagic, or show overlapping exudative and hemorrhagic features [7]. Exudation and associated macular edema may cause gradual visual loss, whereas rupture can produce intraretinal, preretinal, subretinal, or vitreous hemorrhage and abrupt visual deterioration [4]. Hemorrhage or exudation may obscure the aneurysm and mimic other retinal vascular or macular disorders [8]. In an earlier clinical series, hemorrhagic lesions were misdiagnosed at initial presentation in 75% of cases [4].

Observation is appropriate for many RAMs because spontaneous thrombosis and involution can occur [9]. A meta-analysis of 69 studies summarized outcomes after observation, laser photocoagulation, and intravitreal anti-vascular endothelial growth factor therapy [10]. Meyer et al. compared laser treatment with observation in symptomatic RAM [11]. Wang et al. also evaluated observation, laser photocoagulation, and anti-vascular endothelial growth factor therapy [12]. Direct navigated laser photocoagulation has been reported as a primary treatment for RAM [13]. A long-term comparative case series included observation, laser photocoagulation, and vitrectomy [14]. Another clinical series reported visual and anatomical improvement after focal laser treatment, with anti-vascular endothelial growth factor therapy used selectively for macular exudation [15]. Vitreoretinal surgery is reserved for selected eyes with severe hemorrhagic complications [14]. Because randomized treatment trials are lacking, treatment selection remains individualized [9].

The present study therefore evaluated serial changes in BCVA, CMT, aneurysm thickness, and hard exudate area after laser photocoagulation in a small cohort of patients with exudative RAM. We also examined the relationship between pretreatment fovea-macroaneurysm (F-M) distance and macular thickening and compared outcomes between eyes with and without documented RAM-related hemorrhage. Because all participants received laser treatment and no untreated comparator was available, the analyses were considered exploratory and were intended to describe associations rather than establish causal efficacy.

2. Materials and Methods

2.1 Study Design and Participants

This single-center retrospective comparative case series included consecutive patients with exudative retinal arterial macroaneurysm who underwent laser photocoagulation at the Affiliated Hospital of Qingdao University. The clinical record review period extended from 29 April 2024, the date of symptom onset in the first included patient, to 11 May 2026, when the last included patient completed the available 3–6-month clinical follow-up. During this period, 12 consecutive patients (12 eyes) met the eligibility criteria. All 12 eligible patients were included, and no patient was excluded. Each patient contributed one study eye. The cohort comprised 1 man and 11 women, aged 62–79 years; 7 right eyes and 5 left eyes were affected. Lesions were located on a superior temporal branch in 6 eyes and an inferior temporal branch in 6 eyes. Diagnosis was established by dilated fundus examination, FFA, and spectral-domain OCT. Clinical and imaging data were collected retrospectively from 15 July to 28 July 2026. The authors had access to information that could identify individual participants during data extraction; however, the analytic dataset was subsequently de-identified, and no directly identifiable information was retained after data collection.

Eligibility required (1) a clinically and angiographically confirmed RAM, (2) exudation and/or macular thickening attributable to the RAM, (3) treatment with a single session of laser photocoagulation, and (4) complete BCVA and imaging data at baseline, 1 week, 1 month, and 2 months. Exclusion criteria were media opacity preventing adequate imaging or laser delivery at the time of treatment, concurrent retinal detachment, diabetic retinopathy, age-related macular degeneration, severe systemic multiorgan dysfunction, incomplete records, or loss to the scheduled efficacy follow-up.

Eyes were classified according to whether RAM-related hemorrhage had been documented on pretreatment fundus examination or imaging records. Seven eyes formed the hemorrhagic group and five formed the nonhemorrhagic group. All patients in the hemorrhagic group were observed until the accumulated blood had spontaneously resorbed sufficiently to allow clear lesion visualization and safe laser delivery. For all analyses, baseline measurements were those obtained on the day of laser treatment. Quantitative outcomes were evaluated through Month 2, and treatment-related complications and recurrence were assessed over the available 3-6-month clinical follow-up.

The study was approved by the Ethics Committee of the Affiliated Hospital of Qingdao University (approval No. QYFY WZLL 50411) and was conducted in accordance with the Declaration of Helsinki. Only previously collected clinical and imaging data were analyzed, and no additional examination or change in treatment was introduced for research purposes. Because of the retrospective nature of the study, the requirement for informed consent was waived by the Ethics Committee.

2.2 Laser Photocoagulation

Laser procedures were performed using the Lumenis Vision One multiwavelength retinal laser system. Compound tropicamide eye drops were used for mydriasis, and oxybuprocaine hydrochloride eye drops were administered for topical anesthesia. The RAM was localized with a wide-field retinal contact lens.

The laser wavelength was 561 nm, power was 150–220 mW, and exposure duration was 0.2 seconds. A combined circumferential and direct photocoagulation protocol was used. First, 200-micrometer low-energy spots producing a mild grade 1 pale-gray retinal reaction were placed circumferentially around the RAM. Direct photocoagulation was then applied to the RAM using 300-500-micrometer spots to produce a grade 2–3 moderate whitening response. All eyes received one treatment session and no additional laser session during the efficacy follow-up.

After laser photocoagulation, all patients were documented as having received oral Yunnan Baiyao capsules as part of routine clinical care rather than as a study-assigned intervention. Detailed information on the dose, duration of treatment, and medication adherence was not consistently available in the retrospective records. Patients were also advised to avoid strenuous physical activity. Scheduled follow-up visits were performed at 1 week, 1 month, and 2 months after laser photocoagulation.

2.3 Outcomes and Image Measurement

BCVA, CMT, aneurysm thickness, and retinal hard exudate area were measured at baseline and at every efficacy follow-up. Pretreatment F-M distance was measured once as an anatomical variable. Change values were calculated as baseline minus follow-up values; therefore, positive values indicated improvement for all four longitudinal outcomes.

BCVA was measured with a standard decimal visual acuity chart. Numeric decimal acuities were converted to logMAR as -log10(decimal acuity). Based on quantitative low-vision measurements reported by Schulze-Bonsel et al., counting-fingers and hand-movements acuities were assigned logMAR values of 1.85 and 2.28, respectively [16]. The same conversion rule was applied at all visits before statistical analysis.

OCT measurements were obtained with a Heidelberg Spectralis spectral-domain OCT system. For this study, CMT was operationally defined as full retinal thickness at the foveal center on the registered B-scan rather than as the mean thickness of an ETDRS central subfield. Aneurysm thickness was defined as the maximum full retinal thickness on a B-scan passing through the center of the RAM; this measurement therefore represented RAM-associated cross-sectional retinal thickness. F-M distance was measured as the straight-line distance from the foveal center to the center of the RAM on the calibrated fundus reference image linked to the OCT examination. Follow-up scans used the device follow-up function, consistent scan orientation, and automatic image registration to reproduce the baseline location.

Hard exudate area was assessed on images acquired with the ZEISS CLARUS 500 ultra-widefield true-color fundus imaging system. A circular region with an 8-mm radius centered on the fovea was used. Hard exudate boundaries were delineated semiautomatically in ImageJ version 1.54, with image scale calibration used to convert pixel area to square millimeters [17]. All image-based measurements were performed by one ophthalmologist on coded images using the same measurement rules and device-integrated tools. The examiner was not involved in the subsequent statistical calculations.

2.4 Statistical Analysis

Continuous variables are presented as median and IQR. Quartiles were calculated using the (n + 1)p rule to match the descriptive convention used in the source analysis. Because of the small group sizes and skewed measurements, rank-based methods were used throughout. Overall and within-group changes across the four visits were screened using the Friedman test. When longitudinal change was assessed relative to baseline, exact two-sided Wilcoxon signed-rank tests were used and the three baseline-to-follow-up comparisons within each outcome were adjusted with the Holm method.

Between-group differences in baseline variables and absolute change values were tested with exact permutation versions of the Mann-Whitney U test. The three follow-up comparisons within each outcome were Holm-adjusted. Cliff's delta was calculated as an effect-size measure; positive values indicated greater improvement in the nonhemorrhagic group. Percentage changes in CMT and aneurysm thickness were analyzed as sensitivity analyses because the groups differed numerically in pretreatment values. Associations with F-M distance were assessed using Spearman rank correlation and permutation-based two-sided P values. The nine exploratory correlations involving postoperative CMT change, three visits, and three analysis populations were Holm-adjusted as one family.

Analyses were performed using Python 3.12.13 with NumPy 2.3.5 and pandas 3.0.1. Exact tests used exhaustive permutations when computationally feasible; overall Spearman P values used 100,000 reproducible permutations. Adjusted two-sided $P < 0.05$ was considered statistically significant. No formal sample-size calculation was performed because this was a retrospective exploratory study of a rare condition.

3. Results

3.1 Participants and Baseline Characteristics

A total of 12 consecutive patients (12 eyes) were assessed for eligibility. All 12 patients met the eligibility criteria and were included in the analysis; no patient was excluded. All included eyes had complete measurements at baseline, 1 week, 1 month, and 2 months. The hemorrhagic group comprised seven eyes, and the nonhemorrhagic group comprised five eyes. No statistically significant between-group difference was detected in baseline BCVA, CMT, aneurysm thickness, hard exudate area, or F-M distance (all exact $P >= 0.098$; Table 1 and Fig. 1). Nevertheless, the nonhemorrhagic group had numerically greater pretreatment CMT and aneurysm thickness, which was considered when interpreting absolute change values.

Table 1
Baseline ocular characteristics according to hemorrhage status

Variable	Hemorrhagic (n = 7)	Nonhemorrhagic (n = 5)	Exact P
BCVA (logMAR)	1.850 (1.000-2.280)	1.000 (0.500–1.850)	0.098
Central macular thickness (μm)	367.0 (323.0-536.0)	421.0 (397.5-564.5)	0.321
Aneurysm thickness (μm)	483.0 (441.0-670.0)	635.0 (422.5–870.0)	0.343
Hard exudate area (mm^2)	27.513 (1.575–54.777)	21.635 (0.983–50.141)	0.845
F-M distance (μm)	5479 (2369–6753)	3251 (2751–5213)	0.432

Data are median (IQR). Between-group P values were calculated using an exact permutation Mann-Whitney U test. F-M, fovea-macroaneurysm.

3.2 Overall Short-term Outcomes

Across the entire cohort, all four outcomes changed over time (Friedman P < 0.001 for each outcome; Table 2 and Fig. 2). Median BCVA improved from 1.850 logMAR (IQR, 1.000-2.172) at baseline to 0.849 (0.398–1.850), 0.548 (0.301–1.226), and 0.412 (0.172–0.925) at 1 week, 1 month, and 2 months, respectively. Each comparison with baseline remained significant after Holm correction (adjusted P = 0.004, 0.001, and 0.001, respectively).

Table 2
Overall longitudinal visual and anatomical outcomes

Outcome	Baseline	1 week	1 month	2 months	Friedman P
BCVA (logMAR)	1.850 (1.000-2.172)	0.849 (0.398–1.850); Adj. P = 0.004	0.548 (0.301–1.226); Adj. P = 0.001	0.412 (0.172–0.925); Adj. P = 0.001	< 0.001
CMT(μm)	411.0 (334.0-516.0)	312.0 (260.8-486.8); Adj. P = 0.001	237.5 (202.0-382.2); Adj. P = 0.001	196.0 (185.5–292.0); Adj. P = 0.001	< 0.001
Aneurysm thickness (μm)	560.5 (450.0-680.5)	458.0 (350.2-583.2); Adj. P = 0.001	420.5 (274.5-499.5); Adj. P = 0.001	324.0 (253.2-401.8); Adj. P = 0.001	< 0.001
Hard exudate area (mm^2)	24.574 (1.553–50.253)	12.433 (0.516–27.847); Adj. P = 0.003	10.833 (0.436–24.442); Adj. P = 0.003	9.422 (0.231–23.916); Adj. P = 0.001	< 0.001

Data are median (IQR). Adj. P values are Holm-adjusted exact Wilcoxon signed-rank P values for comparison with baseline. CMT, central macular thickness.

Median CMT decreased from 411.0 micrometers (IQR, 334.0-516.0) at baseline to 312.0 (260.8-486.8), 237.5 (202.0-382.2), and 196.0 micrometers (185.5–292.0) at the three follow-up visits. Median aneurysm thickness decreased from 560.5 micrometers (IQR, 450.0-680.5) to 458.0 (350.2-583.2), 420.5 (274.5-499.5), and 324.0 micrometers (253.2-401.8). Median hard exudate area decreased from 24.574 square millimeters (IQR, 1.553–50.253) to 12.433 (0.516–27.847), 10.833 (0.436–24.442), and 9.422 square millimeters (0.231–23.916). All baseline-to-follow-up anatomical comparisons remained significant after Holm correction (adjusted P < = 0.003). Serial color fundus photographs of a representative eye showed progressive regression of the RAM and reduction of macular hard exudates after laser photocoagulation (Fig. 3).

3.3 Association Between F-M Distance and CMT

Pretreatment F-M distance showed a strong inverse correlation with baseline CMT (r_s = -0.963, permutation P < 0.001; Fig. 4A), indicating greater central thickening when the RAM was located closer to the foveal center. Some unadjusted analyses of F-M distance versus CMT reduction yielded nominal P values below 0.05 in the overall cohort at Months 1 and 2; however, none of the nine exploratory follow-up correlations remained statistically significant after Holm correction (all adjusted P > = 0.334; Fig. 4B-D). Thus, the data supported an association with baseline macular involvement but not a reproducible association with the magnitude of post-treatment CMT reduction.

3.4 Comparisons by Hemorrhage Status

Longitudinal distributions of the anatomical measurements within the hemorrhagic and nonhemorrhagic groups are shown in Fig. 5. The nonhemorrhagic group had greater absolute reductions in CMT than the hemorrhagic group at 1 week, 1 month, and 2 months (Holm-adjusted P = 0.009, 0.008, and 0.008, respectively; Table 3 and Fig. 6A). The corresponding Cliff's delta values were 0.886, 1.000, and 1.000, indicating large separation in this sample. Reductions in aneurysm thickness were also greater in the nonhemorrhagic group at all three visits (adjusted P = 0.008, 0.008, and 0.010; Cliff's delta = 1.000, 1.000, and 0.886; Fig. 6B). Sensitivity analyses based on percentage change yielded the same direction and statistical interpretation for CMT and aneurysm thickness (adjusted P < = 0.018).

Table 3
Between-group comparisons of change from baseline

Outcome	Visit	Hemorrhagic (n = 7)	Nonhemorrhagic (n = 5)	Exact P	Holm P	Cliff's delta
BCVA change (logMAR)	1 week	0.602 (0.430–0.850)	0.079 (0.000-0.301)	0.028	0.083	-0.771
BCVA change (logMAR)	1 month	0.979 (0.699–1.026)	0.549 (0.327–0.877)	0.067	0.083	-0.657
BCVA change (logMAR)	2 months	1.280 (0.845–1.327)	0.699 (0.366–1.001)	0.032	0.083	-0.743
CMT reduction (μm)	1 week	11.0 (10.0–83.0)	157.0 (105.0-198.0)	0.009	0.009	0.886
CMT reduction (μm)	1 month	118.0 (98.0-131.0)	213.0 (196.5–233.0)	0.003	0.008	1.000
CMT reduction (μm)	2 months	133.0 (124.0-168.0)	237.0 (206.5–320.0)	0.003	0.008	1.000
Aneurysm-thickness reduction (μm)	1 week	54.0 (27.0–73.0)	194.0 (170.0-226.5)	0.003	0.008	1.000
Aneurysm-thickness reduction (μm)	1 month	92.0 (64.0-151.0)	330.0 (205.0-378.5)	0.003	0.008	1.000
Aneurysm-thickness reduction (μm)	2 months	148.0 (103.0-211.0)	340.0 (264.5-531.5)	0.010	0.010	0.886
Hard-exudate-area reduction (mm^2)	1 week	12.676 (0.607–15.080)	1.316 (0.620–7.207)	0.186	0.557	-0.486
Hard-exudate-area reduction (mm^2)	1 month	12.734 (1.310–16.680)	3.005 (0.717–11.308)	0.250	0.557	-0.429
Hard-exudate-area reduction (mm^2)	2 months	18.091 (1.372–22.230)	10.873 (0.725–20.005)	0.408	0.557	-0.314

Change was calculated as baseline minus follow-up; positive values indicate improvement. Cliff's delta is positive when improvement tends to be greater in the nonhemorrhagic group. Holm adjustment was applied across the three visits within each outcome.

BCVA improvement was numerically greater in the hemorrhagic group, which had worse baseline vision, but the three between-group comparisons did not remain significant after Holm correction (adjusted P = 0.083 at each visit). Hard exudate area reductions did not differ statistically between groups at any visit (adjusted P = 0.557 for all three comparisons; Fig. 6C). Because the exact two-sided Wilcoxon test has

limited attainable significance with only five observations, none of the individual baseline-to-follow-up comparisons within the nonhemorrhagic group reached significance after Holm correction despite consistent directional improvement. Direct between-group estimates and effect sizes were therefore emphasized over within-group significance labels.

3.5 Safety

No recurrent RAM rupture or hemorrhage, secondary retinal injury, macular hole, retinal detachment, or documented disease recurrence occurred during the available 3-6-month follow-up. No patient required additional laser treatment or vitreoretinal surgery during this period.

4. Discussion

This retrospective series showed short-term improvement in visual acuity and anatomical measures after laser photocoagulation for exudative RAM. Across all eyes, BCVA improved and CMT, RAM-associated retinal thickness, and hard exudate area decreased during the 2-month efficacy follow-up. The study also identified a strong inverse association between pretreatment F-M distance and baseline CMT. In direct comparisons, eyes without documented hemorrhage showed greater CMT and aneurysm-thickness reductions than eyes with hemorrhage, whereas between-group differences in BCVA and hard exudate improvement did not remain significant after adjustment for multiple testing.

Laser photocoagulation has been used for symptomatic RAM for several decades, but treatment selection remains individualized because spontaneous involution is common and high-quality comparative evidence is limited [9]. The present study did not include an untreated comparator, so the observed changes cannot be attributed exclusively to laser treatment. Nevertheless, all efficacy baselines were obtained on the day of treatment, after sufficient hemorrhage absorption in the hemorrhagic group, and serial improvement was observed across functional and anatomical outcomes. These findings are consistent with a previous clinical series reporting reduction of macular thickness and improvement in visual acuity after focal laser treatment [15].

The strong inverse correlation between F-M distance and pretreatment CMT is anatomically plausible: leakage arising closer to the fovea may produce greater central retinal involvement. In contrast, F-M distance was not consistently associated with CMT reduction after correction for exploratory multiple testing. Lesion location may therefore be more informative about baseline macular involvement than about the amount of short-term anatomical recovery. This interpretation should remain cautious because the correlation analysis included only 12 eyes and could be sensitive to individual observations.

The larger CMT and aneurysm-thickness reductions observed in the nonhemorrhagic group may reflect biological and clinical differences between presentations. Hemorrhagic RAM may represent a different stage of wall disruption, thrombosis, organization, or surrounding tissue injury. In addition, because laser in the hemorrhagic group was performed only after spontaneous blood absorption, the timing of intervention relative to disease onset may have differed between groups. The nonhemorrhagic group

also had numerically greater baseline CMT and aneurysm thickness, providing more room for absolute reduction. Percentage-change sensitivity analyses supported the same group pattern, but the small sample precluded reliable baseline-adjusted multivariable modeling. The subgroup findings should therefore be regarded as hypothesis-generating rather than as evidence for a treatment-selection rule.

Hard exudate resolution did not differ significantly according to hemorrhage status. Lipid clearance may proceed more slowly than fluid reduction and may depend on the duration of leakage, macrophage-mediated removal, systemic vascular factors, and baseline exudate burden. The short 2-month efficacy window may therefore be insufficient to characterize the full course of hard exudate regression. Visual recovery also did not differ significantly between groups after multiplicity correction. Worse baseline vision in the hemorrhagic group and the ordinal nature of very-low-vision categories may have contributed to the larger numerical logMAR improvement in that group.

Several limitations should be considered. First, this was a retrospective single-center study of only 12 patients without an observation or alternative-treatment comparator. Selection bias, regression to the mean, and spontaneous RAM involution cannot be excluded. Second, treatment was delayed in hemorrhagic eyes until blood absorption permitted safe laser delivery; the waiting interval was not analyzed and may have introduced stage-related confounding. Third, systemic vascular factors such as hypertension, dyslipidemia, and arteriosclerotic disease were not available for stratified analysis. Fourth, efficacy follow-up was limited to 2 months, although safety observations extended to 3–6 months. In addition, all patients received oral Yunnan Baiyao capsules after laser photocoagulation as part of routine clinical care. Because there was no comparison group that received laser photocoagulation without this concomitant medication, the independent contributions of laser treatment, Yunnan Baiyao, and the natural course of retinal arterial macroaneurysm could not be distinguished. The observed changes should therefore not be attributed exclusively to laser photocoagulation. Fifth, image measurements were performed by one ophthalmologist, formal intraobserver reproducibility was not assessed, and CMT and aneurysm thickness were operational point or cross-sectional measures rather than standardized reading-center metrics. Finally, several outcomes and subgroup comparisons were explored. Holm adjustment reduced false-positive risk, but the small sample produced imprecise estimates and limited power, especially in the five-eye nonhemorrhagic group.

Larger prospective multicenter studies should use standardized ETDRS visual acuity testing, prespecified central-subfield and RAM morphometric measurements, documented systemic vascular covariates, and longer follow-up. A concurrent observation or alternative-treatment group would be required to estimate comparative treatment effects.

5. Conclusion

Laser photocoagulation was associated with short-term visual and anatomical improvement in 12 eyes with exudative RAM, with no serious treatment-related complication observed during follow-up. Eyes without documented hemorrhage showed greater reductions in CMT and aneurysm thickness than eyes

with hemorrhage, whereas BCVA and hard exudate improvement did not differ significantly after multiplicity correction. Pretreatment F-M distance was strongly associated with baseline CMT but not with subsequent CMT reduction after correction for exploratory testing. Because of the retrospective uncontrolled design and small sample, these findings should be interpreted as preliminary.

Abbreviations

BCVA, best-corrected visual acuity;

CMT, central macular thickness;

FFA, fundus fluorescein angiography;

F-M distance, fovea-macroaneurysm distance;

IQR, interquartile range;

OCT, optical coherence tomography;

RAM, retinal arterial macroaneurysm.

Declarations

CRediT authorship contribution statement

Haolin Yu: Conceptualization, Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing.

Xiaoqian Zhong: Investigation, Data curation, Validation, Writing – review & editing.

Hao Zhuang: Investigation, Data curation, Validation, Writing – review & editing.

Xian Yang: Formal analysis, Validation, Writing – review & editing.

Haoyan Zhang: Data curation, Validation, Visualization, Writing – review & editing.

Lin Yao: Investigation, Data curation, Validation, Writing – review & editing.

Haiqing Bai: Conceptualization, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

All authors critically reviewed and revised the manuscript for important intellectual content, approved the final version for submission, and agreed to be accountable for all aspects of the work.

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Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution

Haolin Yu: Conceptualization, Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing.Xiaoqian Zhong: Investigation, Data curation, Validation, Writing – review & editing. Hao Zhuang: Investigation, Data curation, Validation, Writing – review & editing.Xian Yang: Formal analysis, Validation, Writing – review & editing.Haoyan Zhang: Data curation, Validation, Visualization, Writing – review & editing.Lin Yao: Investigation, Data curation, Validation, Writing – review & editing.Haiqing Bai: Conceptualization, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

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Figures

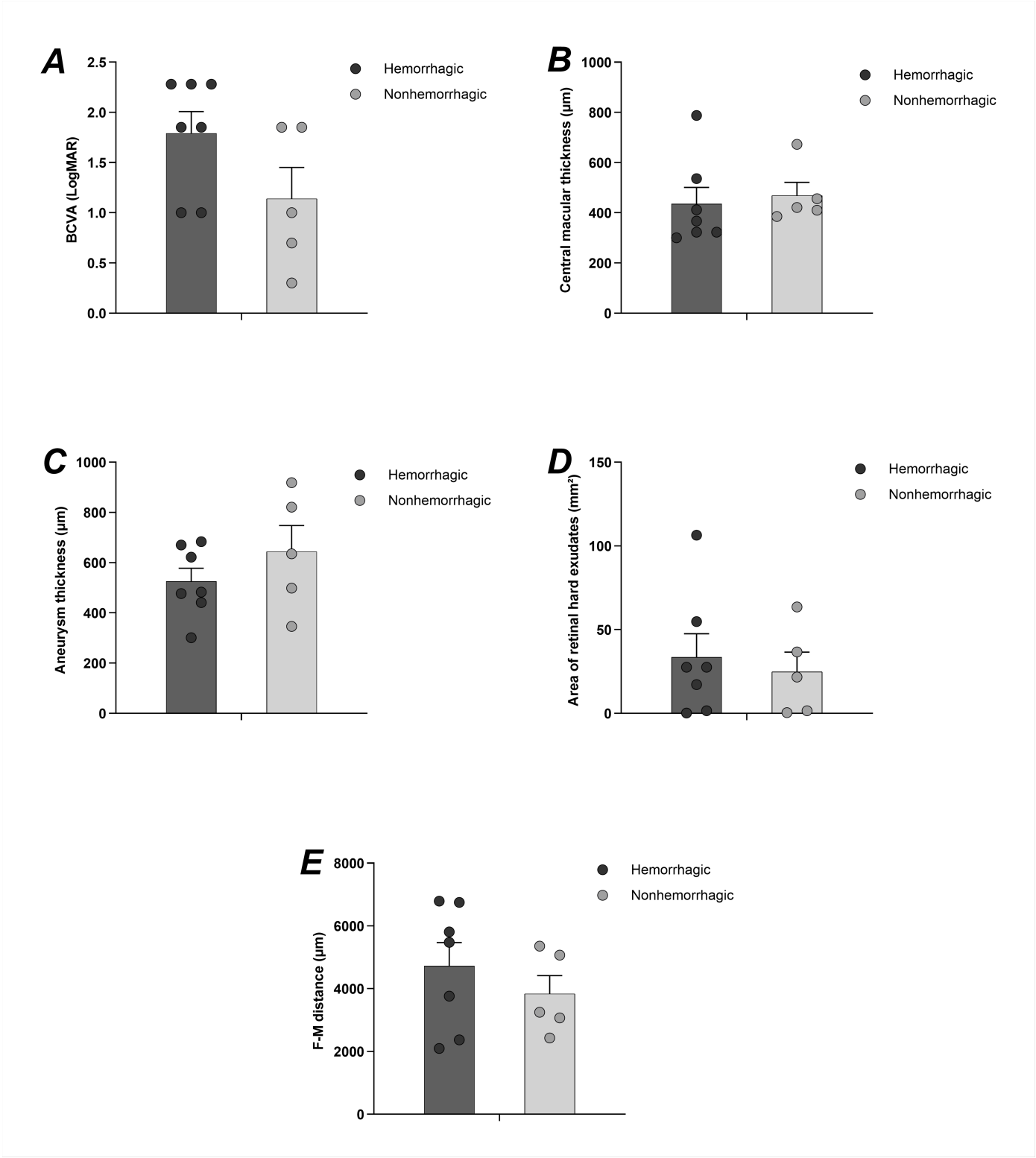


Figure 1

Baseline ocular characteristics according to hemorrhage status.

Plots compare baseline BCVA (A), CMT (B), aneurysm thickness (C), hard exudate area (D), and F-M distance (E) between the hemorrhagic and nonhemorrhagic groups. Bars represent means, error bars represent standard deviations, and dots represent individual measurements. No measured baseline

variable differed significantly between groups. BCVA, best-corrected visual acuity; CMT, central macular thickness; F-M distance, fovea-macroaneurysm distance; logMAR, logarithm of the minimum angle of resolution.

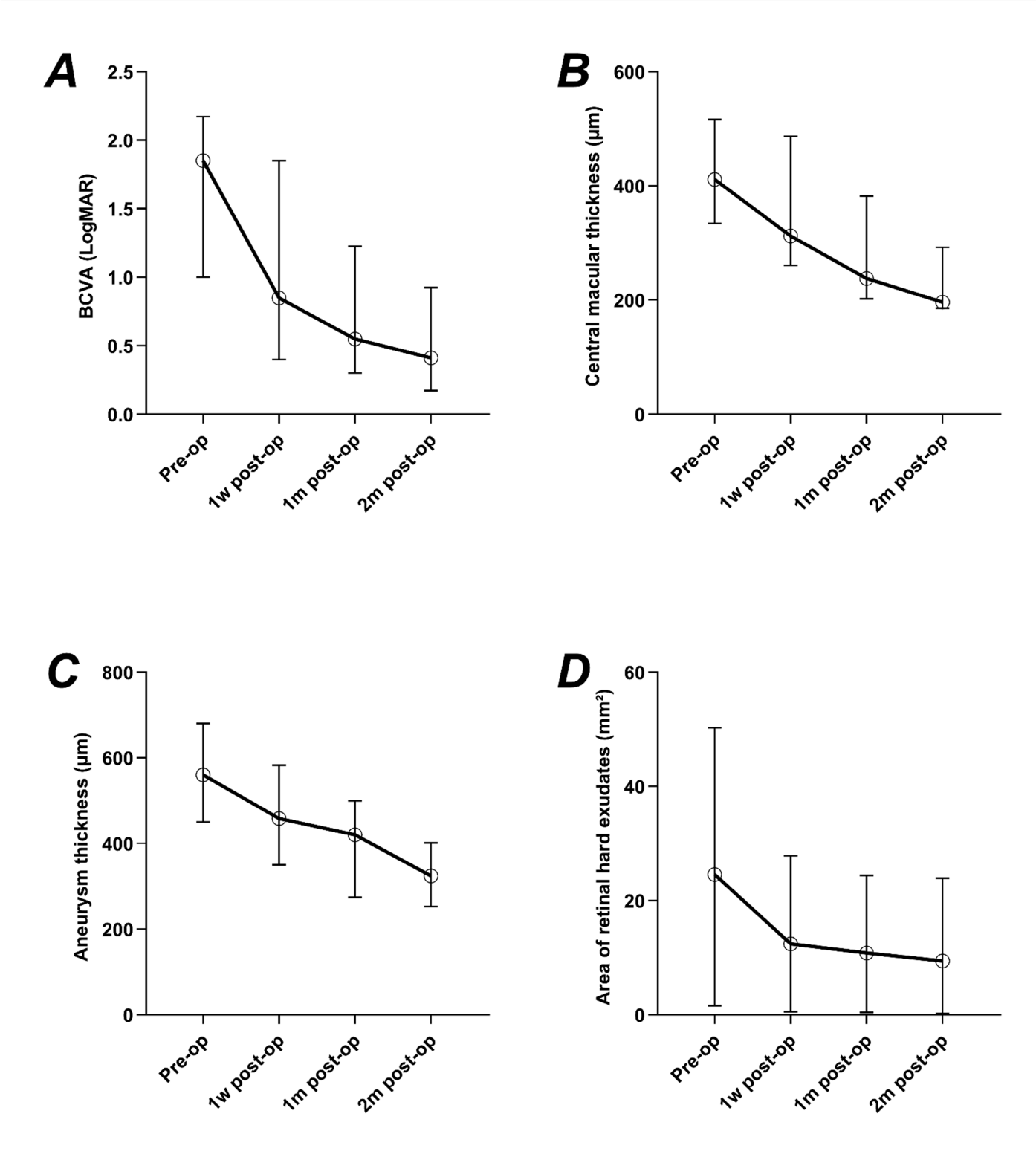


Figure 2

Temporal trends in clinical outcomes after laser photocoagulation.

Longitudinal changes in BCVA expressed as logMAR (A), CMT (B), aneurysm thickness (C), and retinal hard exudate area (D) at baseline and at 1 week, 1 month, and 2 months after laser photocoagulation. Data points represent medians, and error bars represent interquartile ranges. Lower logMAR values indicate better visual acuity; decreases in the anatomical measurements indicate improvement. BCVA, best-corrected visual acuity; CMT, central macular thickness; IQR, interquartile range; logMAR, logarithm of the minimum angle of resolution.

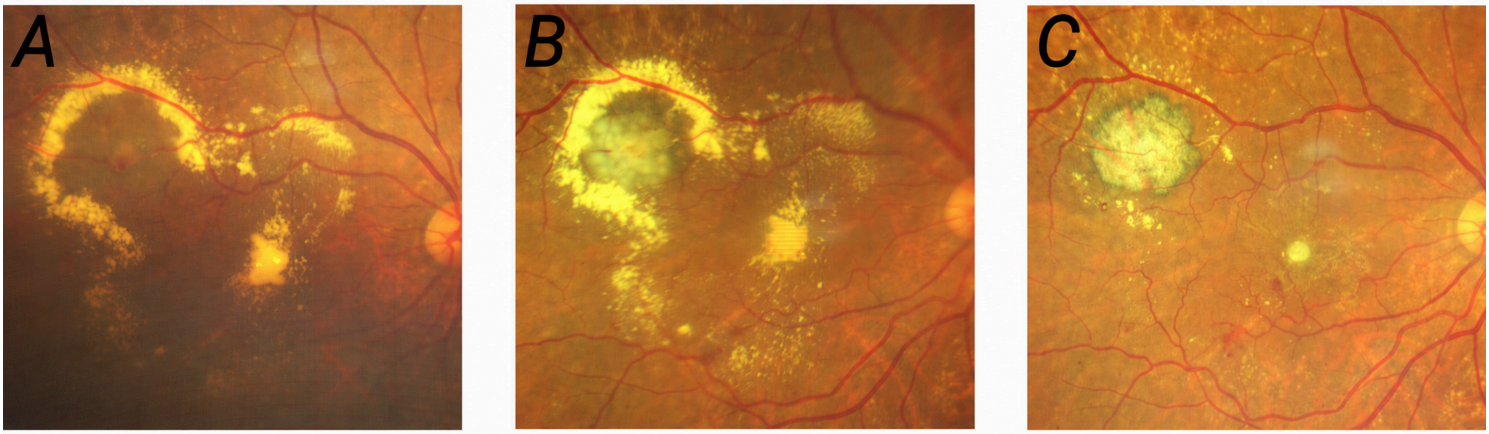


Figure 3

Serial color fundus photographs of a representative RAM case.

At baseline (A), the RAM was surrounded by annular hard exudates involving the macular region. At 1 week after laser photocoagulation (B), gray-white laser reactions were visible over and around the lesion, accompanied by a slight reduction in aneurysm size and redistribution of hard exudates. At 2 months (C), the RAM had regressed, with fibrotic changes at the lesion site and a substantial reduction in macular hard exudates. RAM, retinal arterial macroaneurysm.

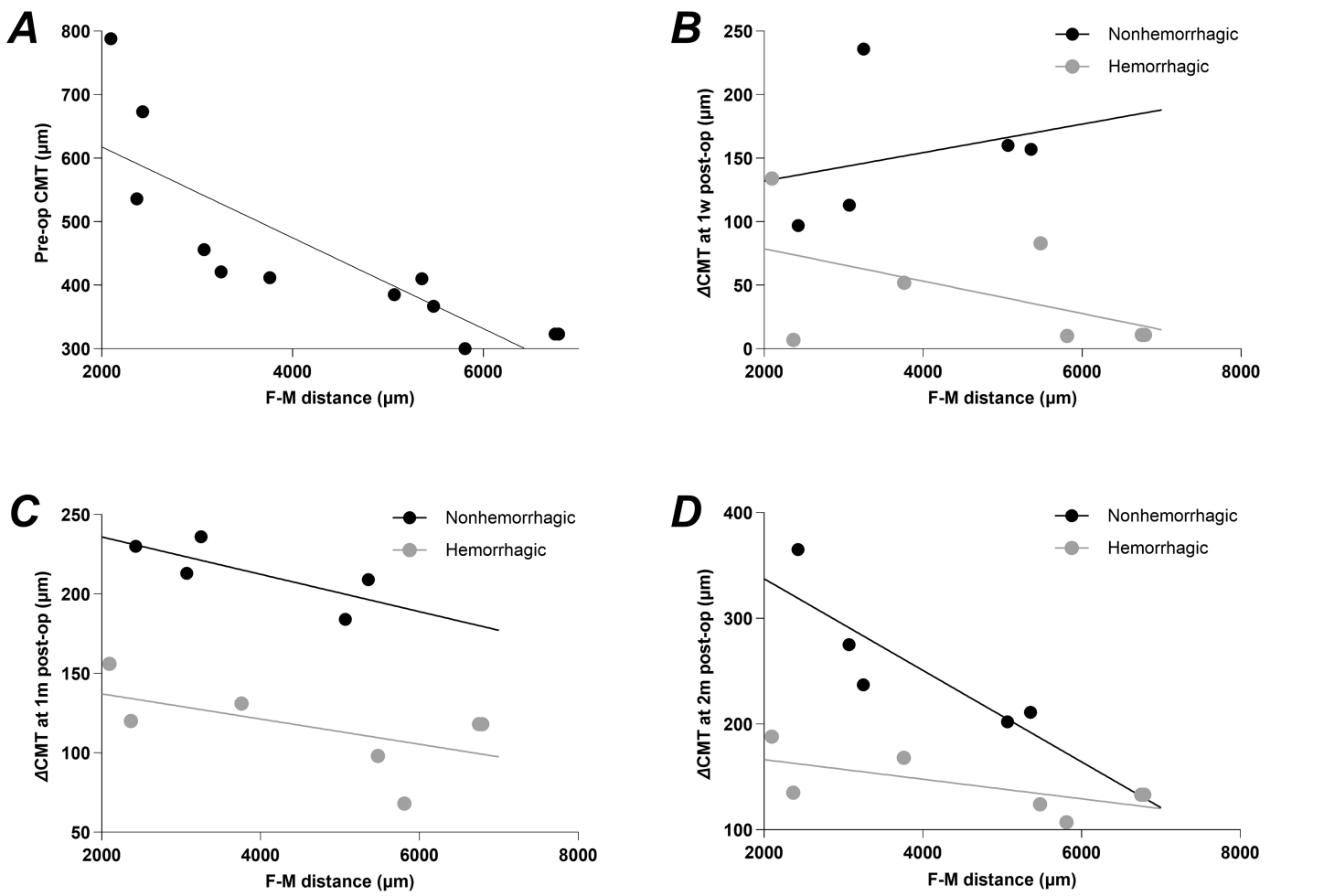


Figure 4

Relationship between F-M distance and CMT.

Baseline CMT was strongly inversely correlated with pretreatment F-M distance in the overall cohort (A). Panels B-D show CMT reduction at 1 week, 1 month, and 2 months, respectively, according to F-M distance and hemorrhage status. None of the exploratory follow-up correlations remained statistically significant after Holm correction. In panel A, black dots represent all included eyes. In panels B-D, black dots indicate nonhemorrhagic eyes and gray dots indicate hemorrhagic eyes. The fitted line in panel A represents the overall cohort, whereas the fitted lines in panels B-D illustrate within-group trends. CMT, central macular thickness; F-M distance, fovea-macroaneurysm distance.

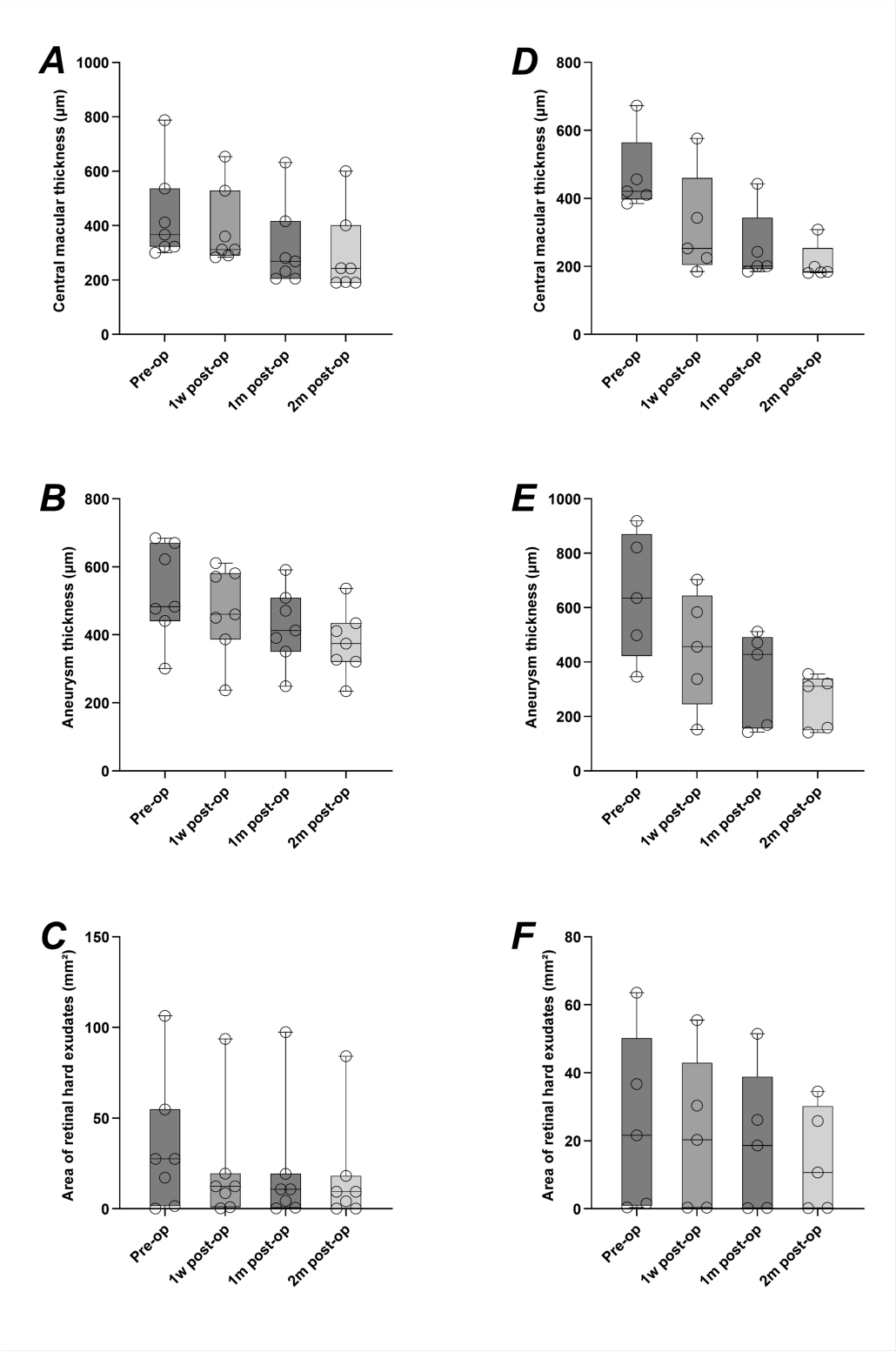


Figure 5

Longitudinal anatomical outcomes within each hemorrhage-status group.

Boxplots show CMT (A and D), aneurysm thickness (B and E), and hard exudate area (C and F) at baseline and at 1 week, 1 month, and 2 months after laser photocoagulation. Panels A-C represent hemorrhagic eyes, and panels D-F represent nonhemorrhagic eyes. Center lines indicate medians, boxes

indicate interquartile ranges, whiskers indicate the observed ranges, and open circles represent individual measurements. CMT, central macular thickness; IQR, interquartile range.

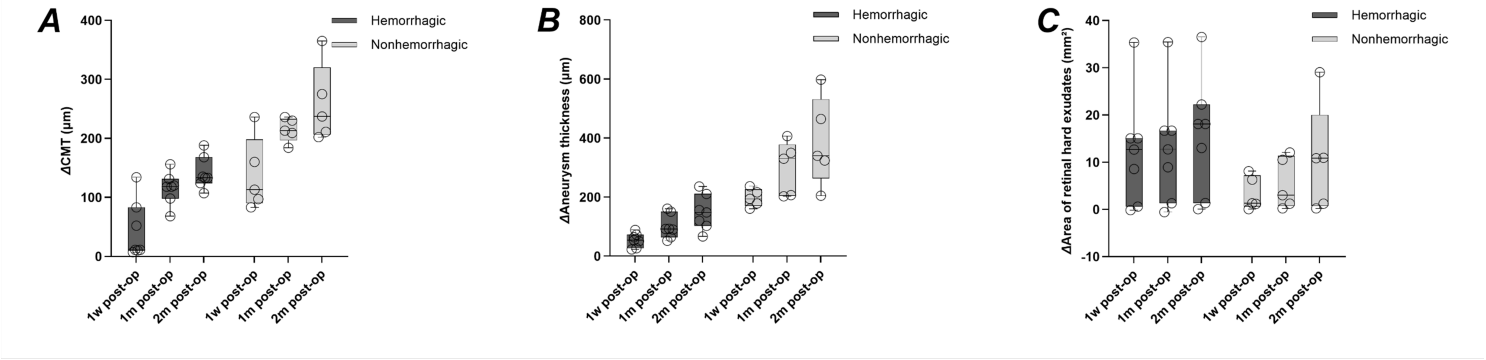


Figure 6

Between-group comparisons of anatomical changes from baseline.

Boxplots compare changes from baseline at 1 week, 1 month, and 2 months between hemorrhagic and nonhemorrhagic eyes for CMT (A), aneurysm thickness (B), and hard exudate area (C). Changes were calculated as baseline minus follow-up values; therefore, positive values indicate reductions from baseline. Center lines indicate medians, boxes indicate interquartile ranges, whiskers indicate the observed ranges, and circles represent individual measurements. CMT and aneurysm-thickness reductions were greater in the nonhemorrhagic group at each visit after Holm correction, whereas hard-exudate-area reduction did not differ significantly between groups. CMT, central macular thickness; IQR, interquartile range.