Choroidal Morphological Characteristics and Vascular Features in Patients with the Idiopathic Macular Hole

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ABSTRACT

Purpose: We aimed to evaluate choroidal morphological and vascular features of patients with idiopathic macular holes (MHs) compared to contralateral fellow eyes and control eyes.

Methods: This comparative, observational study reviewed 32 patients with unilateral MHs who underwent MH surgery. Choroid was imaged using the EDI mode of spectral-domain (SD) OCT. Choroidal thicknesses (CT) were measured from the subfoveal region. Choroidal vascularity index (CVI) was calculated with ImageJ software.

Results: A significant choroidal thinning was observed in eyes with MHs compared to contralateral fellow eyes (242.2 ± 31.4 µm vs. 267.1 ± 26.1 µm, p<0.0001) and control eyes (242.2 ± 31.4 µm vs. 263.7 ± 37.9 µm, p=0.016). Subfoveal CVI was lower in the eyes with MHs compared to the fellow eyes (61.2% vs. 64.4%, p<0.0001) and control eyes (61.2% vs. 64.8%, p<0.0001). There was a significant relationship between subfoveal CVI and final LogMAR best-corrected visual acuity (BCVA) (standardized coefficients beta= -0.248, p=0.014). MH was successfully closed following the surgery in 27 patients (84.4%). In the persistent holes, preoperative duration of decreased visual acuity was significantly longer (p=0.0004), and the diameter of MH was significantly larger than in those with closed holes (p=0.009).

Conclusion: This study showed that the mean CT and CVI values were decreased in eyes with MHs. These findings may be due to mechanical damage in the process of MH formation or metabolic changes in oxygen and other nutrients in the fovea. Higher CVI values were associated with more significant improvement in final BCVA after MH surgery.

Keywords: Macular hole, Choroidal thickness, Choroidal vascularity index, Surgery, Outcome

INTRODUCTION

Idiopathic macular hole (MH) is a vitreomacular interface disorder with a complex and not fully understood mechanical pathogenesis, which is believed to involve anteroposterior traction and/or tangential traction exerted by the posterior vitreous cortex at the fovea, as well as a loss of function of Muller cells ripped from the fovea.[1-3] Its prevalence is estimated at 3.3 cases per 1000 persons over 55 years of age, with a female-to-male ratio of 3.3/1. The population-based annual incidence of idiopathic MH is 8.69 eyes per 100,000 individuals.[4]

Idiopathic MH was first classified by Donald Gass on fundus observation in 1988.[5] The introduction of optical coherence tomography (OCT) in clinical practice led to a new classification for MH which is the international vitreomacular traction study group classification of vitreomacular adhesion, traction, and MH in 2013.[6] The authors also classified MHs based on their aperture size (minimum hole diameter) measured on OCT, which was defined as small (<250 µm), medium (250-400 µm), and large (>400 µm).[6] However, there are some efforts to update the possible definition of large MHs, which are 500 µm or 650 µm thresholds beyond which are expected poorer anatomical and functional outcomes.[7,8]

Despite technological advances in instrument design of pars plana vitrectomy (PPV) and surgical techniques developments, the postoperative visual acuity (VA) is poor in some cases, even if successful MH closure.[9] Foveal microstructure restoration and function were evaluated after idiopathic MH surgery.[10] Disruption of the outer retina, including the external limiting membrane (ELM), the ellipsoid zone (EZ), and the photoreceptors with

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respect to the visual prognosis have been investigated in previous OCT based studies.[11,12] However, there is limited information regarding the quantitative evaluation of the preoperative status of the choroidal microvasculature in eyes with idiopathic MHs. With the development of OCT imaging technology, improvements in the visualization of the choroid by enhanced depth imaging OCT (EDI-OCT) and swept source-OCT have allowed the investigation of choroidal features in patients with MHs. Given choroidal vascular dysfunction is associated with many pathological conditions, it is imperative to have detailed in vivo baseline measurements of the choroidal morphometric and vascular features in patients with MHs.

To the best of our knowledge, no study has quantified the choroidal vasculature changes in eyes with MHs and/or the possible association between preoperative choroidal vascular parameters and the postoperative VA so far. Herein, we present choroidal morphological and vascular features of patients with MHs compared to contralateral fellow eyes and healthy eyes to investigate the association of preoperative microvascular choroidal parameters with postoperative anatomical and functional outcomes and foveal healing.

MATERIALS AND METHODS

Study design and Subjects

This is a comparative, observational, retrospective study including patients with MHs who underwent PPV at Kayseri City Training and Research Hospital. This study adhered to the Declaration of Helsinki's tenents and was approved by the Local Ethics Committee (approval number: 142998788).

We reviewed the medical records of patients who underwent PPV for the idiopathic MH surgery between May 2018 and February 2022. Patients who had idiopathic full-thickness MHs caused visual complaints and had at least 3 months of postoperative follow-ups were evaluated. Accordingly, 32 eyes of 32 patients were included in the final analysis. Demographic characteristics, including age, sex, laterality, and the duration of decreased visual acuity were evaluated in all patients. Each patient underwent a complete ophthalmic examination, including slit-lamp examination, intraocular pressure (IOP) measurement, fundoscopy, preoperative axial length (AL) measurement, and spectral-domain (SD) OCT (Spectralis HRA + OCT; Heidelberg Engineering, Heidelberg, Germany). Type of primary surgery (vitrectomy alone or combined cataract surgery) was also recorded. Best-corrected visual acuity (BCVA) was assessed with ETDRS charts. The BCVA, slit-lamp examinations, fundoscopy, and OCT examinations were performed before surgery and 2 weeks, 1 month, 3 months, and every 3 months in the following follow-ups after surgery. The inclusion criterion was an idiopathic full-thickness MH confirmed on OCT leading to central scotomata and deterioration of vision. The aperture diameter was measured at the minimal linear extent of the MH width in the retina. The basal hole diameter of the MH was measured as the linear length of foveal detachment at the level of the retinal pigment epithelium. Anatomical surgical success was defined as the closure of MHs with a flattened and reattached hole rim along the whole circumference of the MH. Eyes with macular disease, such as age-related macular degeneration, diabetic retinopathy, a spherical equivalent refractive error > ± 4.0 diopters, glaucoma, recent (within 3 months) intraocular surgery or previous vitreoretinal surgery, and other marked ocular complications were excluded. Patients with systemic diseases such as uncontrolled diabetes, uncontrolled hypertension, incomplete follow-up, and poor-quality OCT images were also excluded.

Image Acquisition and Data Analysis

All of the OCT imaging was performed by the same experienced technician (SE), which provides data standardization for retrospective research. The macular OCT was obtained using the SD-OCT (version 6.0.0.2) comprising 25 sections and 768 A-scans in a 20 × 20 degrees rectangle encompassing the macula. The choroid was imaged using the SD-OCT's EDI mode after pupil dilation. The patient's eye fixated on the internal fixation light of OCT and a reverse image was obtained so that the chorioretinal interface was adjacent to the zero delay. Each set of images comprised 13 sections and 768 A-scans in a 5 × 30 degrees rectangle with 122 μm between consecutive scans and 8.8 mm scan in length. The OCT images were assessed in analysis when automated real-time averaging ≥ 75 times and the images' quality scores bigger than 20 dB (range: 0–40 dB) according to the manufacturer's recommendation were used in the analysis. Choroidal thickness (CT) was defined as the vertical distance between the external limit of the Bruch's membrane and the choroidal-scleral interface. CT was manually evaluated at subfoveal, nasal, and temporal regions of 750 μm from the fovea center using the SD-OCT software's caliper tool (Figure 1). The average of subfoveal, nasal, and temporal CT measurements was used for mean CT. All CT measurements were applied by two independent experienced ophthalmologists (NB and CO). Inter-examiner reproducibility of all manual measurements was evaluated by the intraclass correlation coefficient (ICC). If IC values greater than 0.80 were accepted as good agreement. When

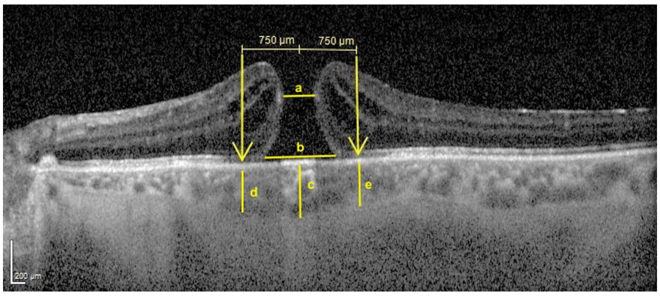

Figure 1: *Representative figure showing measurements on spectral-domain optical coherence tomography scan passing through the fovea (a=hole size; b=basal hole size; c=subfoveal choroidal thickness, d=nasal choroidal thickness, e=temporal choroidal thickness).*

the ophthalmologists' measurements were not consistent, they were repeated until good agreement was achieved and the average of both measurements was used for the final analysis.

Choroidal Vascular Structure Evaluation

The horizontal EDI-OCT scan passing through the fovea of each eye was chosen for image analysis. The EDI-OCT scans were binarized using the software ImageJ software (Version 1.53, National Institutes of Health, Bethesda, MD, USA; https://imagej.nih.gov/ij/) after converting to 8 bits to distinguish between the vascular and stromal areas of the choroid. Image binarization was obtained using the Niblack auto local threshold technique.[13] The total choroidal area, the vascular area, and the stromal area were then calculated for the fovea within the central 1500 µm zone. Bright pixels showed the choroidal stromal area, whereas dark pixels showed the vascular area (Figure 2). The choroidal vascularity index (CVI) was determined as the ratio between the vascular area and the total choroidal area.

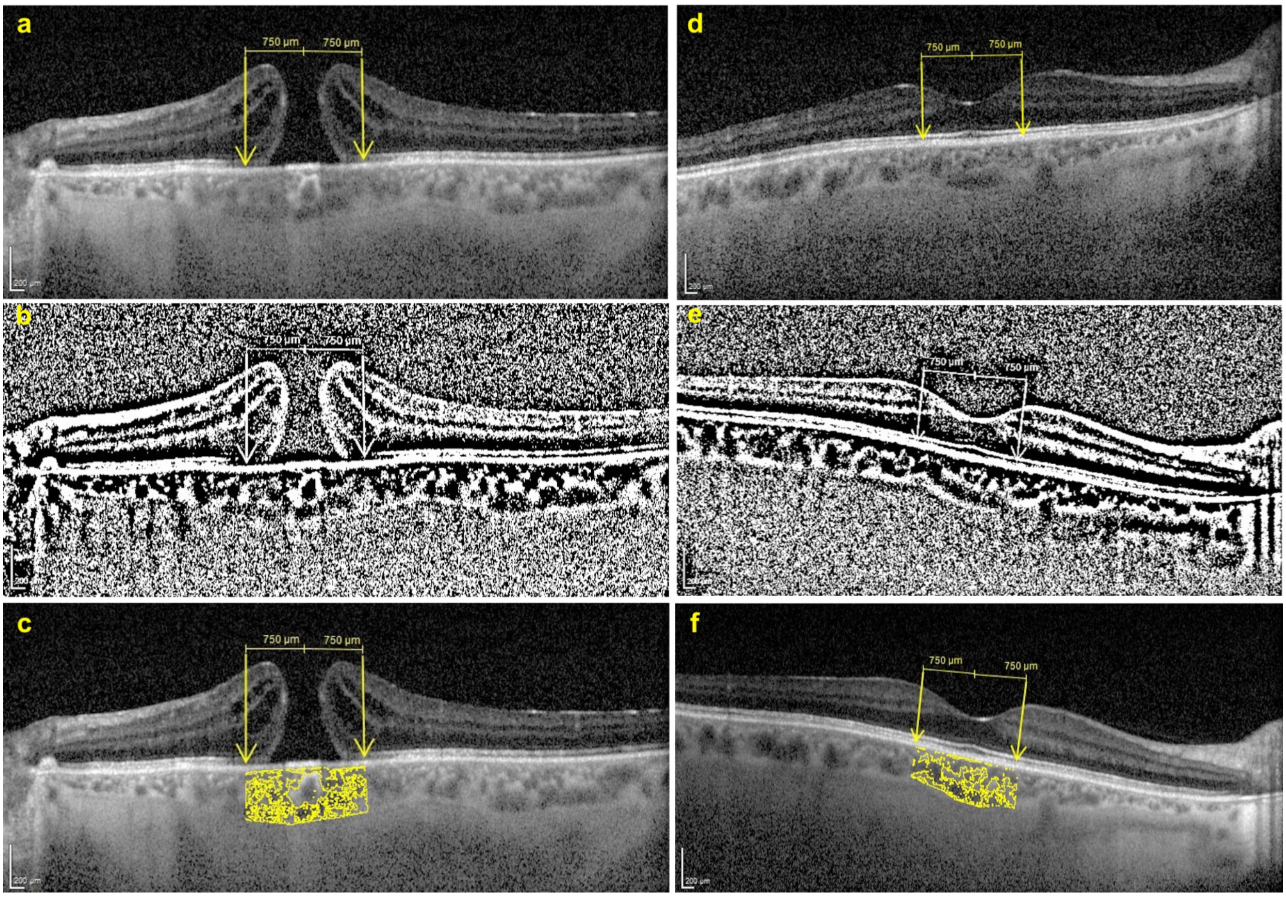

Figure 2: *Spectral-domain optical coherence tomography (SD-OCT) images of a 73-year-old female patient show choroidal vascularity index calculations from a marked 1500 µm central subfoveal area (a, d). The EDI-OCT sections present the binarization by ImageJ software using the Niblack auto local threshold (b, e). Black areas refer to the vascular area, and white areas refer to the stromal area in the choroid. Superimposed images of the binarized subfoveal segments over the EDI-OCT scans indicate the optically segmented choroid into two parts by yellow border lines, vascular and stromal areas (c, f). In the present patient, the subfoveal choroidal vascularity index decreased in the left eye, which developed a macular hole (a-c), compared to the fellow eye (d-f) (61.2% vs. 68.1%, respectively).*

Surgical Technique

Surgery was performed using the Constellation Vision System with a standard 25-gauge 3-port PPV (Alcon Laboratories, Inc., Fort Worth, TX, USA) in all patients. The phakic patients had at least early-stage cataracts, phacoemulsification and intraocular lens implantation were performed in the same surgical setting. After a core vitrectomy, the posterior hyaloid was completely removed with the assistance of 0.1 mL (4 mg) triamcinolone acetonide (Kenacort-A; 40 mg/mL; Bristol-Myers Squibb). Combined dye based on a mix of 0.15% trypan blue and 0.025% brilliant blue G (Membrane Blue-Dual; DORC–Dutch Ophthalmic Research Center, Zuidland, Netherlands) was used to enhance the visualization of the ILM, and the nitinol flex loop was gently performed to create an edge of the flap of ILM. After an edge of the flap was made from typically temporal to the macula, the uplifting end of the ILM was caught carefully by forceps and peeled off. ILM was performed in a circumferential pattern of about 2-disk diameters around the foveal area when MHs <400 µm, and about 4-disc diameters centered on the fovea in larger MHs. After removing the ILM, fluid-air exchange (FAX) and intraocular gas tamponade with 20% of sulfur hexafluoride (SF6) were performed, and the patients were encouraged to remain in postoperative face-down positioning for at least 5 days after surgery. Sclerotomies were checked and sutured if needed at the end of the surgery.

Outcome Measures

The primary outcome measure was defined as the successful anatomical closure of MHs after surgery and the secondary outcome measures were determined as the restoration of foveal tissue and BCVA improvement. The patients were sub-classified into 2 groups based on postoperative BCVA for a threshold of 0.7 logMAR to reveal a possible relationship between preoperative parameters and postoperative BVCA.

Statistical Analysis

The SPSS program for Mac OS version 26.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Quantitative variables were presented as the mean ± standard deviation and categorical variables were expressed as frequencies and percentages. The Kolmogorov-Smirnov test and Levene's test were used to assess the normal distribution and the homogeneity of variances of the variables, respectively. The paired 2-tailed t-test was used to assess the significance of differences between patients' eyes with the MH while independent samples t-test for the significance between the right eye of healthy participants and each eye of patients with an MH. Similarly, McNemar's test and Fisher's exact test were used to assess the comparison of categorical variables. Pearson's correlation coefficient investigated the relationship between patients' preoperative parameters and successful closure of MHs. A relationship between preoperative duration of decreased visual acuity and changes in choroidal structure and final BCVA measurements was examined by linear regression analysis. Adequate sample size was determined using power analysis with G*power 3.1. It analyzed that at least 27 eyes should be in each group to calculate at least 1 micron in CT difference on OCT between eyes with MHs, fellow eyes, and control eyes for 0.80 power with 0.5 effect size and 5% margin of error. A p-value<0.05 was considered as statistical significance.

RESULTS

Patients' characteristics

Of the 45 subjects initially enrolled, 13 were excluded based on the exclusion criteria: a spherical equivalent refractive error > ± 4.0 diopters (n = 3), poor-quality OCT images (n = 4), incomplete follow-up (n = 2), diabetic retinopathy (n = 1), glaucoma (n = 1), recent intraocular surgery (n = 1), and age-related macular degeneration (n = 1). Of the 32 included patients, 12 (37.5%) were male, and 20 (62.5%) were female, with a mean age of 69.2 ± 5.1 years. The mean patients' follow-up was 14.8 ± 4.7 months. No significant difference was observed between the patients with MHs and the control group regarding gender (62.5% of the MH patients and 56.3% of the control group were females, p=0.799), and age (69.2 ± 5.1 years vs. 67.3 ± 5.3 years, respectively; p=0.148). IOP, spherical equivalent, AL, and pseudophakic rates were also similar among eyes with MHs, fellow eyes, and control eyes (for all comparisons, p<0.05), whereas the mean BCVA was significantly low in eyes with MHs compared to fellow eyes, and control eyes (p<0.0001). In eyes with MHs, the duration of decreased visual acuity was 11.4 ± 7.1 months, and 46.9% of the eyes (15/32) had right-sided. The aperture hole diameter and the basal hole diameter were 534.9 ± 123.1 µm and 1009.1 ± 258.9 µm, respectively. All patients underwent MH surgery, and simultaneous cataract surgery was performed on 6 of them in the same session. The MH was successfully closed following the surgery in 27 patients (84.4%). In the persistent holes, the preoperative duration of decreased visual acuity was significantly longer (p=0.0004), and the diameter of MH was significantly larger than in those with closed holes (p=0.009). In the correlation analysis, there was a negative relationship between the duration of decreased visual acuity, aperture hole diameter, and successful hole close (r= −0.592, p=0.0003 for the duration of decreased visual acuity and successful hole close, and r= −0.455, p<0.009 for aperture hole diameter and successful hole close). The area under the receiver operating characteristic (ROC) curve was 0.90 (95% confidence interval 0.79–1.00, p=0.005) for the aperture diameter of MH with a cutoff value of 645.0 mm, a sensitivity of 100%, and a specificity of 89.0% for predicting closure rate after MH surgery (Figure 3). In the follow-up period, the EZ and ELM recovered in 11 of 27 patients (40.7%) whose MHs were closed. In the eyes with recovered EZ and ELM after MH surgery, aperture hole diameter and basal hole diameter were significantly lower than in eyes that had not recovered EZ and ELM (p=0.0002, p<0.0001, respectively). The baseline characteristics and examination parameters of the eyes are summarized in Table 1.

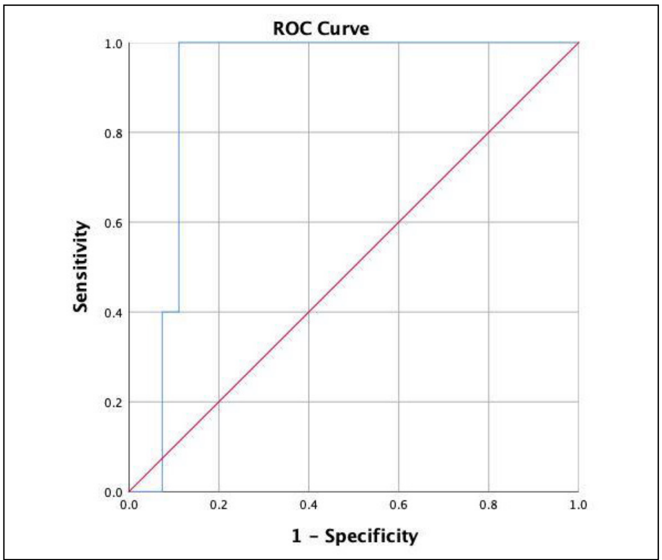

Figure 3: *The receiver operating characteristic (ROC) curve for aperture diameters of MH predicting initial closure rate. The area under the curve was 0.90 (95% confidence interval 0.79–1.00) with a cutoff value of 645.0 mm. Predicting sensitivity and specificity were 100.0% and 89.0%, respectively (p=0.005).*

Comparison of choroidal thickness and choroidal vascular measurements

The mean CT values of the eyes with MHs were lower compared with fellow eyes of the patients (242.2 ± 31.4 µm vs. 267.1 ± 26.1 µm, p<0.0001) and control eyes (242.2 ± 31.4 µm vs. 263.7 ± 37.9 µm, p=0.016). Similarly, significant choroidal thinning was observed in eyes with MHs compared to the fellow eyes and control eyes on CT measurements performed from subfoveal, at 750 µm distances in the nasal and temporal regions (for all, p<0.05). No significant difference was found between the CT measurements of the fellow and control eyes (for all, p>0.05).

The percentage of the subfoveal stromal area/vascular area ratio in the eyes with MHs was higher compared with fellow eyes of the patients (63.5% vs. 55.4%, p<0.0001) and control eyes (63.5% vs. 54.5%, p<0.0001). Similarly, the subfoveal CVI values of the eyes with MHs were lower compared to the fellow eyes 61.2% vs. 64.4%, p<0.0001) and control eyes (61.2% vs. 64.8%, p<0.0001). In the eyes with recovered EZ and ELM after surgery, CVI was

Table 1: *Demographic features and ocular characteristics of the patients and control group, eyes with macular holes, fellow eyes, and control eyes*

Variables	Eyes with macular holes (n = 32, mean ± SD)	Fellow eyes (n = 32, mean ± SD)	Control eyes (n = 32, mean ± SD)	*P*-value*
Age (years)	69.2 ± 5.1	69.2 ± 5.1	67.3 ± 5.3	-, 0.148[a], 0.148[b]
Gender (male/female)	12/20	12/20	14/18	-, 0.799[c], 0.799[d]
Spherical equivalent, (D)	-0.33 ± 1.4	-0.41 ± 1.1	-0.18 ± 0.8	0.593[e], 0.779[a], 0.326[b]
BCVA (LogMAR)	1.10 ± 0.17	0.01 ± 0.03	0.02 ± 0.04	***<0.0001***[e], ***<0.0001***[a], 0.529[b]
IOP (mmHg)	15.6 ± 2.6	16.1 ± 1.7	16.0 ± 2.7	0.205[e], 0.608[a], 0.829[b]
Axial length (mm)	23.2 ± 0.69	23.1 ± 0.74	23.5 ± 0.78	0.266[e], 0.206[a], 0.059[b]
Pseudophakia rate	12/32	14/32	10/32	0.500[f], 0.793[c], 0.439[d]

BCVA: best-corrected visual acuity, **D:** diopter, **IOP:** intraocular pressure,
*Statistically significant p-values are shown in bold and italic font
[a]Comparison between eyes with macular holes and control eyes (independent samples t-test)
[b]Comparison between fellow eyes and control eyes (independent samples t-test)
[c]Comparison between eyes with macular holes and control eyes (Fisher's exact test)
[d]Comparison between fellow eyes and control eyes (Fisher's exact test)
[e]Comparison between eyes with macular holes and fellow eyes (paired 2-tailed t-test)
[f]Comparison between eyes with macular holes and fellow eyes (McNemar's test)

significantly higher than in eyes that had not recovered EZ and ELM (p=0.003). No significant difference was found between the subfoveal choroidal characteristics of the fellow eyes of the patients and control eyes (for all comparisons, p<0.05). Table 2 and Figure 4 summarize the CT and choroidal vascular measurements of the eyes with MHs, the fellow eyes, and the control eyes. The ICC for the mean of each manually calculated measurement in our study showed excellent inter-grader reliability agreement (for all measurements, ICC>0.879).

A relationship between preoperative parameters and postoperative BVCA

The BCVA significantly improved from preoperative 1.10 ± 0.17 logMAR to postoperative 0.80 ± 0.31 logMAR at the last visit (p<0.0001). In the multiple linear regression analysis, the duration of decreased visual acuity and subfoveal CVI had the predictor value for the final BCVA measurements (adjusted R^2: 74.9%, F=43.8, p<0.0001). In the stepwise regression model, which was adjusted for the effects of ocular biometrics on choroidal parameters such as age, gender, refractive error, and AL, a positive and significant relationship was found between the duration of preoperative decreased visual acuity and postoperative final LogMAR BCVA measurements (standardized coefficients beta=0.814, p<0.0001), whereas there was a negative and significant relationship between subfoveal CVI and final LogMAR BCVA measurements (standardized coefficients beta= -0.248, p=0.014). In the subgroup analysis, the duration of preoperative decreased visual acuity, the aperture diameter of the MH, basal hole diameter, and the percentage of the mean stromal/vascular area were significantly lower in eyes with postoperative BVCA less than or equal to 0.7 LogMAR (p<0.0001, p=0.007, p=0.002, and p=0.016, respectively), whereas the CVI was significantly higher (p=0.016).

DISCUSSION

The management of MH has come a long way from the time of Kelly and Wendel, who were the first to describe PPV as a promising treatment option with the successful closure of the MHs in 1991.[14] Since that time, numerous contributions have been made to the surgical procedure such as internal limiting membrane (ILM) peeling with gas or air tamponade to optimize success rates, showing the anatomical MHs closure rates > 90% after primary surgery.[15,16] Small gauge vitrectomy (25- or 27-gauge) can be helpful for less trauma to the ocular surface and a reduced amount of irrigation fluid, resulting in stabilized ocular pressure and earlier recovery of visual acuity. The intraocular tamponades isolate the macular region from the intraocular fluid, allowing the absorption of the subretinal and intraretinal fluid by RPE and apposing the edges of MH. A recent prospective randomized controlled study showed that air tamponade is inferior to SF6 tamponade for MH ≤400 µm in diameter.[17] The duration of intraocular

Table 2: *The choroidal thickness and choroidal vascular characteristics of the eyes with macular holes, fellow eyes, and the control eyes*

Subfoveal choroidal characteristics	Eyes with macular hole (n = 32, mean ± SD)	Fellow eyes (n = 32, mean ± SD)	Control eyes (n = 32, mean ± SD)	*P*-value[a] (MH eyes vs. fellow eyes)	*P*-value[b] (MH eyes vs. control eyes)	*P*-value[b] (fellow eyes vs. control eyes)
EDI-OCT images' quality scores	24.4 ± 2.9	24.1 ± 2.4	24.5 ± 2.5	0.622	0.928	0.483
Subfoveal choroidal thickness, µm	258.4 ± 31.5	286.4 ± 29.7	281.2 ± 44.9	***<0.0001***	***0.022***	0.590
Nasal 0.75 mm choroidal thickness, µm	234.4 ± 30.9	255.2 ± 30.7	253.5 ± 42.0	***0.0002***	***0.042***	0.852
Temporal 0.75 mm choroidal thickness, µm	233.8 ± 40.7	259.8 ± 34.6	256.3 ± 39.8	***<0.0001***	***0.029***	0.706
Mean choroidal thickness, µm	242.2 ± 31.4	267.1 ± 26.1	263.7 ± 37.9	***<0.0001***	***0.016***	0.672
Total choroidal area, mm^2	0.393 ± 0.049	0.434 ± 0.045	0.425 ± 0.062	***<0.0001***	***0.025***	0.523
Vascular area, mm^2	0.241 ± 0.032	0.279 ± 0.027	0.275 ± 0.038	***<0.0001***	***<0.0001***	0.618
Stromal area, mm^2	0.152 ± 0.019	0.155 ± 0.019	0.150 ± 0.026	0.126	0.721	0.416
Stromal area/vascular area (%)	63.5 ± 5.0	55.4 ± 2.6	54.5 ± 4.0	***<0.0001***	***<0.0001***	0.284
Choroidal vascularity index (%)	61.2 ± 1.8	64.4 ± 1.1	64.8 ± 1.7	***<0.0001***	***<0.0001***	0.262

[a]Paired samples t-test
[b]Independent samples t-test

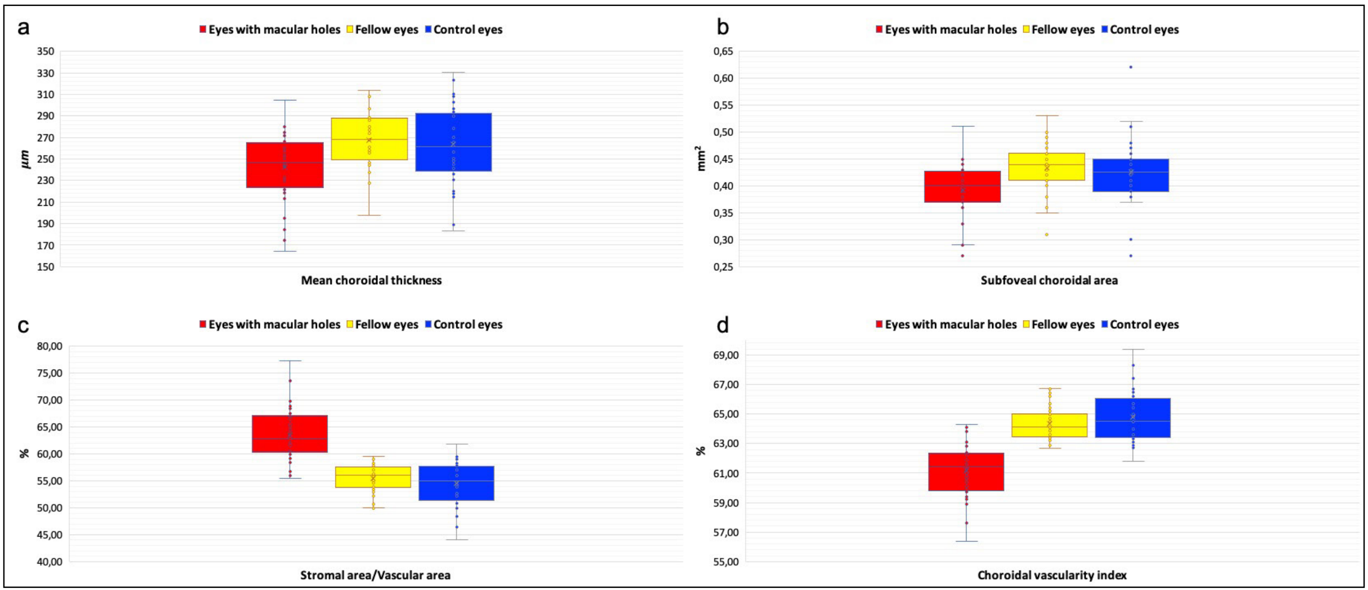

Figure 4: *Composite box plots demonstrate the measurements of the eyes with macular holes, compared to fellow eyes, and age- and gender-matched control eyes for choroidal thickness (a), subfoveal choroidal area (b), stromal area/vascular area (c), choroidal vascularity index (d). Please note that all these measurements showed statistically significant changes in the eyes with macular holes, compared to fellow eyes, and age- and gender-matched healthy control eyes (for all, p<0.05).*

gas tamponades following vitreoretinal surgery was 18 days for 30% SF6, 34.5 days for 20% hexafluoroethane (C2F6), and 67.7 days for 15% perfluoropropane (C3F8).[18] Among these gases, a short-acting tamponade agent, which maintains the isolation effect in the macular region, is desired to provide minimum time for impaired vision and restriction from driving and air travel. Therefore, PPV combined with ILM peeling followed by SF6 gas tamponade is the most common surgical procedure for MHs today. In addition, variations of the inverted internal limiting membrane flap technique showed promising results for large MHs.[16,19] Also, early repeat PPV with the extension of the ILM peeling seems to be an optimal surgical technique to achieve secondary closure.[19] In this study, a standard surgical technique was the 25-gauge PPV combined with ILM peeling followed by 20% SF6 gas tamponade and postoperative face-down positioning for at least 5 days. ILM peeling was performed at about 2-disk diameters when MHs <400 µm, and about 4-disc diameters for larger MHs. With this surgery, we were able to achieve MH closure in 27 of 32 patients (84.4%). This study's results showed that the aperture diameter of MH in eyes with persistent holes was significantly larger than in those with closed MHs. A relatively low anatomical success rate may be related to the higher hole diameter in our patients compared to previous studies.[15,16] Similarly, a relatively low rate of recovered EZ and ELM after surgery in the eyes with successful hole closure could be associated with the same reason.

The connection between the duration of symptoms and postoperative visual outcome is controversial in the literature.[20,21] We think that this inconsistency in the literature is associated with the subjective estimation of the duration of symptoms by the patient. Indeed, many patients who suffered from MHs cannot remember exactly the onset of symptoms, especially in elderly patients with a healthy contralateral eye. Therefore, a detailed medical history is crucial to determine the exact duration of preoperative symptoms. Our study result showed that the duration of symptoms was a prognostic factor for final BVCA and significantly correlated with postoperative visual improvement. Consistent with the above findings, in the subgroup analysis, the duration of preoperative decreased visual acuity, the aperture diameter of the MH, and basal hole diameter were also significantly lower in eyes with better postoperative BVCA on the threshold of 0.7 LogMAR (Table 3).

Several studies have investigated the retinal configuration,[22] microvasculature,[23] and function[14] as preoperative predictive measures of MH using microperimetry, focal electroretinogram, OCT, and OCT angiography, and searched for prediction of the visual outcome after surgery. Because the choroid, the most vascular tissue in the eye, is essential for maintaining retinal homeostasis, and a critical function of the choroid is to support the high metabolically active photoreceptor cells located in the outer retina by delivering oxygen and nutrients and removing waste

Table 3: *Comparison of preoperative parameters between eyes with best-corrected visual acuity (LogMAR) less than or equal to 0.7 and eyes with best-corrected visual acuity (LogMAR) greater than 0.7 at the last visit postoperatively*

Preoperative Variables	BCVA (LogMAR)≤0.7 postop. 3 months	BCVA (LogMAR)> 0.7 postop. 3 months	*P*-value*
Number of patients	14	18	-
Age (years)	70.0 ± 3.7	68.6 ± 6.0	0.446[a]
Gender (male/female)	5/9	7/11	0.854[b]
Laterality (right/left)	9/5	6/12	0.153[b]
Axial length (mm)	23.2 ± 0.83	23.2 ± 0.60	0.879[a]
Spherical equivalent, (D)	-0.56 ± 1.61	-0.15 ± 1.26	0.954[a]
IOP (mmHg)	15.4 ± 2.2	15.8 ± 2.8	0.619[a]
Duration of decreased VA (M)	5.7 ± 4.9	15.8 ± 5.1	***<0.0001***[a]
Aperture hole diameter (µm)	468.1 ± 113.8	587.0 ± 105.9	***0.007***[a]
Basal hole diameter (µm)	855.5 ± 232.6	1128.5 ± 215.3	***0.002***[a]
Subfoveal CT (µm)	260.0 ± 28.9	256.2 ± 35.6	0.805[a]
Nasal 0.75 mm CT (µm)	235.1 ± 36.5	233.8 ± 26.72	0.820[a]
Temporal 0.75 mm CT (µm)	239.2 ± 35.4	226.8 ± 46.9	0.262[a]
Mean CT (µm)	244.3 ± 27.2	239.4 ± 37.0	0.676[a]
Subfoveal choroidal area (mm^2)	0.394 ± 0.059	0.392 ± 0.040	0.774[a]
Subfoveal vascular area (mm^2)	0.245 ± 0.039	0.237 ± 0.025	0.436[a]
Subfoveal stromal area (mm^2)	0.149 ± 0.020	0.155 ± 0.017	0.506[a]
Stromal/vascular area (%)	61.0 ± 3.6	65.4 ± 5.2	***0.016***[a]
Choroidal vascularity index (%)	62.1 ± 1.4	60.4 ± 1.9	***0.016***[a]

BCVA: best-corrected visual acuity, **CT:** choroidal thickness, **D:** diopter, **M:** months**, VA**: visual acuity
***Statistically significant *p*-values are shown in bold and italic font.
[a]Mann-Whitney U test
[b]Fisher's exact test

products, CT is a widely studied in MH eyes. Previous studies and a recent meta-analysis reported that the CT was significantly decreased in idiopathic MH eyes.[24,25] Consistent with the results of previous studies, this study showed a significant decreased CT in all three locations of the subfoveal area in eyes with MHs. Kim et al.[24] reported the thick choroid as a protective factor for final BCVA and visual improvement after MH surgery. However, the previous studies have not had a detailed description of the architectural features of the stromal and vascular parameters in the choroid. Our study results demonstrated that the preoperative higher subfoveal CVI in eyes with MHs had better visual acuity after surgery. Consistent with this result, preoperative CVI was significantly higher in eyes that had recovered EZ and ELM after surgery compared to those where not. Moreover, subfoveal CVI and the duration of preoperative decreased visual acuity had the predictor values for the final BCVA measurements in the linear regression model with suppressing confounder variables such as age, gender, refractive error, and AL. In the subgroup analysis, the CVI was also significantly higher in eyes with better postoperative BVCA on the threshold of 0.7 LogMAR (Table 3). These findings could be attributed to the mechanical breakdown of the retinal capillary networks during MH formation in the process of dehiscence of the central fovea and metabolic changes in oxygen and other nutrients of the highly active retina as well as to the RPE. Although choroidal changes might be a result of the MH and not necessarily the cause of it, some studies have suggested that choroidal circulation changes precede the MH development. Morgan and Schatz[26] suggested that the first step in the development of the MHs is choroidal vascular changes. The authors reported that the majority of patients with MHs had cardiovascular disease, and decreased subfoveal choroidal circulation was noticed during fluorescein angiography. Allen et al.[27] reported a choriocapillaris perfusion disorder with replacement of the fibroblasts and connective tissue in Nd:YAG laser-induced MHs in monkeys. Aras et al.[28] have reported that patients with MHs had reduced subfoveal choroid circulation compared to controls, using a scanning laser Doppler flowmeter. The authors suggested that decreased choroidal circulation and a thinner choroid can cause macular hypoperfusion and might play a role in increasing the susceptibility of the fovea to damaging factors. Further studies are needed to better understand whether choroidal changes are a risk factor in the development of the MH or whether they develop secondary to the MH.

This study is limited by the retrospective nature, small sample size, and short follow-up periods. The other shortcoming of the study is that the retinal superficial and deep capillary plexuses, and choriocapillaris blood perfusion were not able investigated by OCT angiography in the same patients.

In conclusion, this study's results show that subfoveal CVI and CT were significantly decreased in the eyes with MHs compared with fellow eyes and control eyes. These findings may be due to mechanical damage in the process of MH formation or metabolic changes in oxygen and other nutrients in the fovea. The preoperative duration of decreased visual acuity and aperture hole diameter were associated with postoperative successful MH closure. The preoperative higher subfoveal CVI in eyes with MHs was associated with better visual outcomes after surgery and had the predictor value for the final BCVA measurements.

DECLARATION OF INTEREST

The authors report no conflicts of interest, and they alone are responsible for the content and writing of this article.

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