

FOCAL CHOROIDAL EXCAVATIONS IN A SCREENING COHORT

Fundus Visibility and Structural Remodeling in Younger Adults

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Purpose: To determine how fundus visibility relates to optical coherence tomography–derived morphologic and topographic features of focal choroidal excavation (FCE) and to evaluate systemic and ocular associations in a health-screening cohort.

Methods: The authors analyzed 19,048 individuals undergoing health examinations with spectral domain optical coherence tomography and fundus photography. FCEs were classified as fundus-visible or fundus-invisible. A 1:2 propensity score matching (age/sex) was performed to compare participants with FCE against non-FCE controls. Generalized estimating equations were used to analyze lesion characteristics, systemic comorbidities, and ocular parameters including intraocular pressure, choroidal thickness, and macular degeneration.

Results: The authors identified 252 FCE lesions in 192 participants (1.0%). Compared with matched controls, the FCE group showed no significant differences in systemic comorbidities but had significantly lower intraocular pressure ($P = 0.026$), greater choroidal thickness ($P < 0.001$), and a higher prevalence of macular degeneration ($P = 0.002$). Among FCEs, fundus-visible lesions had greater median horizontal diameter (681.0 vs. 518.0 μm ; $P < 0.001$) and depth (69.5 vs. 45.0 μm ; $P < 0.001$), were located closer to the fovea (611.5 vs. 1,385.0 μm ; $P < 0.001$), and exhibited higher rates of steep slopes (62.5% vs. 42.7%; $P = 0.002$) and outer nuclear layer thickening (61.7% vs. 31.5%; $P < 0.001$) compared with fundus-invisible lesions.

Conclusion: FCE is associated with distinct ocular profiles, including lower intraocular pressure and increased choroidal thickness, independent of systemic risk factors. Fundus visibility indicates larger, deeper, and paramacular lesions with specific structural alterations, underscoring the need to recognize subtle fundoscopic irregularities for early optical coherence tomography detection.

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Focal choroidal excavation (FCE) is a localized, idiopathic concavity of the choroid increasingly recognized through the widespread use of optical coherence tomography (OCT).¹ Although initially described in isolated case reports, FCE is now considered a structural anomaly of potential clinical relevance due to its documented associations with macular diseases such as central serous chorioretinopathy, choroidal neovascularization (CNV), and other pachychoroid spectrum disorders.^{2–4} It is often discovered incidentally, particularly in younger adults, suggesting subclinical or early-stage pathology.^{5,6}

The pathogenesis of FCE remains unclear. Some lesions remain stable,^{1,7} whereas others progress in

shape, size, or develop CNV or subretinal fluid (SRF).^{8–10} However, its prevalence and clinical implications in unselected populations remain poorly defined.

Focal choroidal excavation may appear on fundus photography as punctate pigmentary changes, yellowish-white lesions, or areas of diffuse hyper- or hypopigmentation,^{11–13} but structural confirmation requires OCT.¹² Cube scans detect FCE more sensitively than line scans.^{4,11} Previous studies have shown that pigmentary changes and SRF may be associated with retinal pigment epithelium alteration and choroidal remodeling,^{1,12,14} and Xu et al⁴ reported that such structural stress may promote choroidal ischemia and CNV.

In health screening settings, fundus photography is typically performed, while OCT is not routinely available. We hypothesized that certain FCEs may exhibit visible changes on fundus photographs—such as pigmentary alterations or contour irregularities—and that these visible lesions may correspond to more advanced structural abnormalities on OCT, including outer nuclear layer (ONL) thickening, SRF, or retinal pigment epithelium disruption.

In this study, we evaluated a large screening cohort that underwent standardized 6.0 mm × 6.0 mm macular cube scan OCT, fundus photography, and systemic health assessments. Our objectives were to 1) estimate the prevalence of FCE; 2) compare the morphologic and topographic features of fundus-visible and fundus-invisible lesions, based on post hoc assessment of fundus photographs; and 3) explore systemic associations. We aimed to determine whether fundus visibility—once an FCE is identified on OCT—correlates with structural complexity, and whether this may inform future strategies for selective OCT application in resource-limited screening settings.

Methods

Study Design and Participants

This retrospective observational study included individuals who underwent bilateral fundus photography and spectral domain OCT as part of routine health examinations at Kangbuk Samsung Hospital and Sungkyunkwan University Suwon Health Center between January 1 and December 31, 2024. Eyes with FCE, defined as a choroidal excavation without posterior staphyloma on OCT¹ were included. Individuals with a history of ocular trauma were excluded. The study was approved by the Institutional Review Board of Kangbuk Samsung Hospital (IRB No: KBSMC 2025-02-015) and conducted in accordance

with the tenets of the Declaration of Helsinki. Demographic and systemic data were retrieved from electronic medical records.

Imaging Acquisition and Morphologic and Topographic Analyses

Bilateral color fundus photographs were obtained using nonmydriatic digital fundus cameras (TRC-NW8 and TRC-NW400; Topcon Corp, Tokyo, Japan). Fundus visibility was defined as the presence of a discernible abnormality on color fundus photography at the location of an OCT-confirmed FCE (subtle depigmentation, faint or dark hyperpigmentation, or slight alterations in retinal contour). Two independent retinal specialists (E.K. and S.J.S.), each with more than 15 years of experience, assessed the photographs with reference to the OCT lesion sites. The intergrader agreement was high (97.2%, 245/252 lesions), and discrepancies were resolved by consensus discussion between the two graders.

Spectral domain OCT images were acquired using the SPECTRALIS OCT (Heidelberg Engineering, Heidelberg, Germany) with a 6.0 mm × 6.0 mm horizontal cube-scan protocol (10-μm spacing) in enhanced depth imaging mode. For each eye with FCE, the scan showing the greatest horizontal extent of the lesion was selected. Horizontal dimension was defined as the distance between the two inflection points along the upper margin of the choroid. Vertical depth was measured as the perpendicular distance from this line to the deepest point of the excavation using the built-in caliper tool. Slope steepness from the margin to the base was classified as steep or gradual. A slope was defined as steep if the angle between a reference line connecting both margins and a line extending from the slope base to its apex exceeded 40°. Angles were measured manually using ImageJ software (National Institutes of Health, Bethesda, MD), and the steeper of the two slopes was used for classification. In eyes with FCE, choroidal thickness was measured at the thicker of the two points defined by perpendicular lines from each lesion margin to the outer choroidal boundary. In eyes without FCE, subfoveal choroidal thickness was measured beneath the fovea (Figure 1).

Foveal location was determined using the foveal pit and the hyperreflective Müller cell cone on OCT. The distance from the foveal center to the deepest point of each FCE was measured on en face images using the built-in caliper tool (Figure 1). FCEs were topographically classified according to the early treatment diabetic retinopathy study grid into nine subfields.¹⁵ The central subfield (C) was defined as within 500 μm of

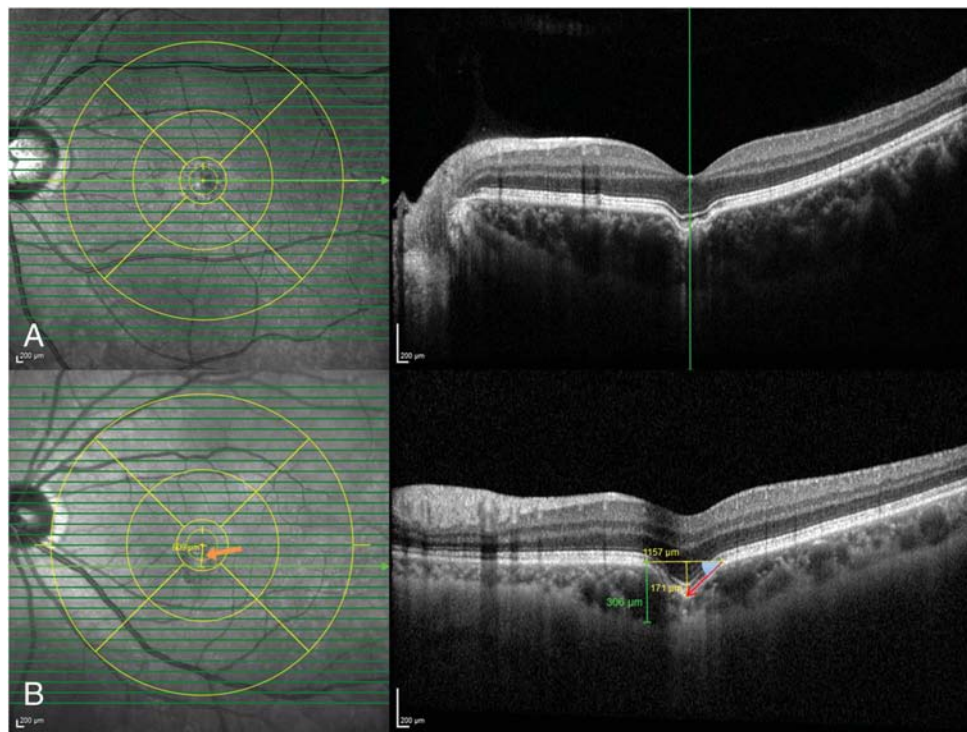
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Fig. 1. Measurement methodology for FCE analysis. **A.** The foveal center was identified on an OCT B-scan based on the location of the foveal pit and the hyperreflective Müller cell cone. This reference point was used to center the ETDRS grid on the en face OCT image. **B.** The distance from the foveal center to the deepest point of the FCE was measured on the en face OCT (orange arrow). Horizontal dimension (yellow line) was defined as the distance between two inflection points at the choroidal margin. Vertical depth (yellow line) was measured as the perpendicular distance from the horizontal reference line to the deepest point of the excavation. Slope steepness was determined by measuring the angle (blue indicator) between the horizontal reference line and the slope line (red arrow); slopes $\geq 40^\circ$ were classified as steep, and those $< 40^\circ$ as gradual. **C.** Choroidal thickness was measured by drawing perpendicular lines from each margin of the FCE to the outer boundary of the choroid; the thicker of the two values was recorded. ETDRS, early treatment diabetic retinopathy study.



the foveal center. The parafoveal inner ring included N1 (nasal), T1 (temporal), S1 (superior), and I1 (inferior) sectors spanning 1,000 to 1,500 μm , while the perifoveal outer ring included N2, T2, S2, and I2 sectors spanning 1,500 to 3,000 μm . Lesions located $> 3,000$ μm from the foveal center were classified as extrafoveal. For extrafoveal lesions, early treatment diabetic retinopathy study sector labels were not applied; instead, directional designations were used: extrafoveal nasal, extrafoveal temporal, extrafoveal superior, and extrafoveal inferior. Focal choroidal excavation location was determined using en face OCT images. Measurements were performed with the Heidelberg SPECTRALIS built-in caliper and corrected for the known scaling factor ($\mu\text{m}/\text{pixel}$) to ensure anatomical accuracy.

Morphologic characteristics of FCEs were further analyzed. While previous studies classified the excavation base as bowl-, cone-, or mixed-shaped,¹⁴ we categorized FCEs into U-, V-, and W-shaped types based on the base contour. The presence of pachyvesels adjacent to or beneath the FCE was assessed, given their reported association with specific FCE phenotypes.¹⁶ Unusual choroidal tissue beneath the excavation was evaluated as described by Ellabban et al¹¹ (Figure 2). Retinal alterations overlying the FCE were also analyzed, including ONL thickening¹⁷ and outer

plexiform layer (OPL)-like reflectivity within the ONL.¹³ A novel morphologic feature identified in this study, termed the “omega sign,” was defined as a dome-shaped elevation of the retinal pigment epithelium connected to the FCE margin, forming an omega (Ω)-like contour on OCT (Figure 3). Retinal layer involvement was assessed by reviewing all horizontal B-scans within the OCT cube; the deepest layer affected by the FCE was categorized as none, Bruch membrane–retinal pigment epithelium complex, ellipsoid zone, ONL, or OPL.

For each patient, laterality and lesion count were recorded, including whether FCEs were unilateral or bilateral and whether multiple FCEs were present in a single eye. In a subgroup with unilateral FCE, choroidal thickness was compared with that of the contralateral eye. Associated retinal or choroidal pathology was also evaluated, limited to findings located within or directly adjacent to the FCE. Subretinal fluid was identified based on the presence of hyporeflective space between the neurosensory retina and underlying structures within the FCE area, and was used to define the nonconforming type.¹ Subretinal hyperreflective material (SHRM) was defined as hyperreflective tissue located between the outer retinal layers and the choroid within the excavation, without inference of specific etiology.

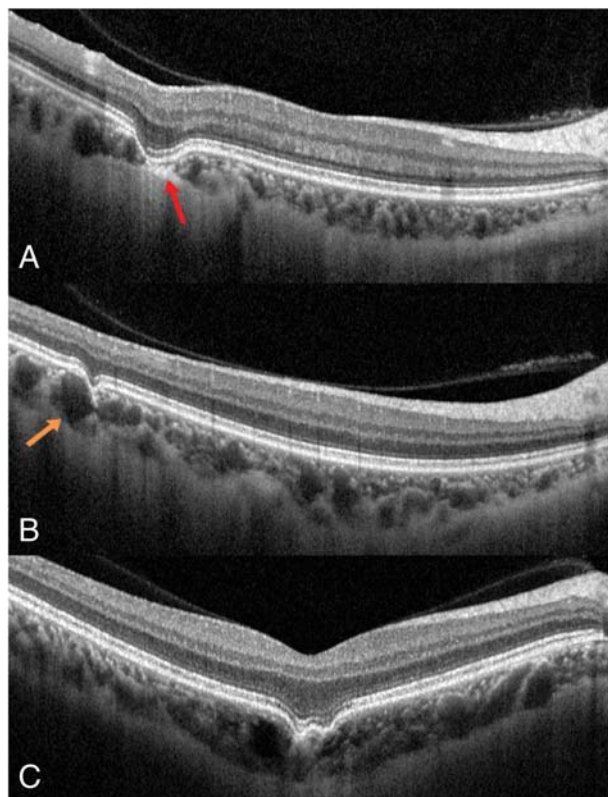


Fig. 2. Representative examples of FCE base configurations and associated features. **A.** U-shaped, **(B)** V-shaped, and **(C)** W-shaped FCEs, categorized according to the contour of the FCE. Red arrow indicates unusual choroidal tissue beneath the FCE, as described by Ellabban et al. Orange arrow indicates a pachyvessel adjacent to the FCE.

Analysis of Structural Abnormalities According to Focal Choroidal Excavation Location

To assess the relationship between lesion location and structural features, post hoc analyses were performed using categorical variables. Lesions were grouped based on radial distance from the foveal center (foveal, parafoveal, perifoveal, extrafoveal) and angular position (central, nasal, temporal, superior, inferior), derived from early treatment diabetic retinopathy study–based coordinates. Associations with the presence of SRF, pachyvessels, unusual choroidal tissue beneath the lesion, OPL hyperreflectivity, ONL thickening, and subretinal SHRM were evaluated.

Comparison Between Participants With and Without Focal Choroidal Excavation

To evaluate systemic and ocular differences between participants with and without FCE, we conducted a 1:2 propensity score matching based on age and sex. All individuals with FCE were retained, and matched controls without FCE were selected from

the same health screening cohort. Systemic comparisons at the individual level included the prevalence of diabetes, hypertension, and dyslipidemia. At the eye level, we assessed best-corrected visual acuity (BCVA), intraocular pressure (IOP), choroidal thickness, and the presence of macular degeneration, graded according to the International Classification of Age-Related Maculopathy and Age-Related Macular Degeneration.¹⁸

Statistical Analysis

Analyses were performed at patient, eye, and lesion levels. Generalized estimating equation accounted for within-subject clustering. Normality and variance homogeneity were tested by Shapiro–Wilk, Kruskal–Wallis, and Levene tests. Continuous variables were compared with Mann–Whitney *U* (between groups) or Wilcoxon signed-rank (paired); categorical variables by chi-square or Fisher exact (with Monte Carlo simulation for sparse data). Post hoc residual analysis identified significant level differences ($>|1.96|$, $P < 0.05$).

After propensity score matching, systemic comorbidities (diabetes, hypertension, and dyslipidemia) were compared using chi-square tests at the patient level. For eye-level comparisons of BCVA, IOP, subfoveal choroidal thickness, and macular degeneration prevalence, linear mixed-effects models were applied for continuous outcomes and generalized estimating equation for binary outcomes, with clustering by patient identifier. In cases where group-level differences were significant for more than one eye-level variable, additional mixed-effects models were constructed to assess potential associations between those variables while accounting for intra-individual correlation.

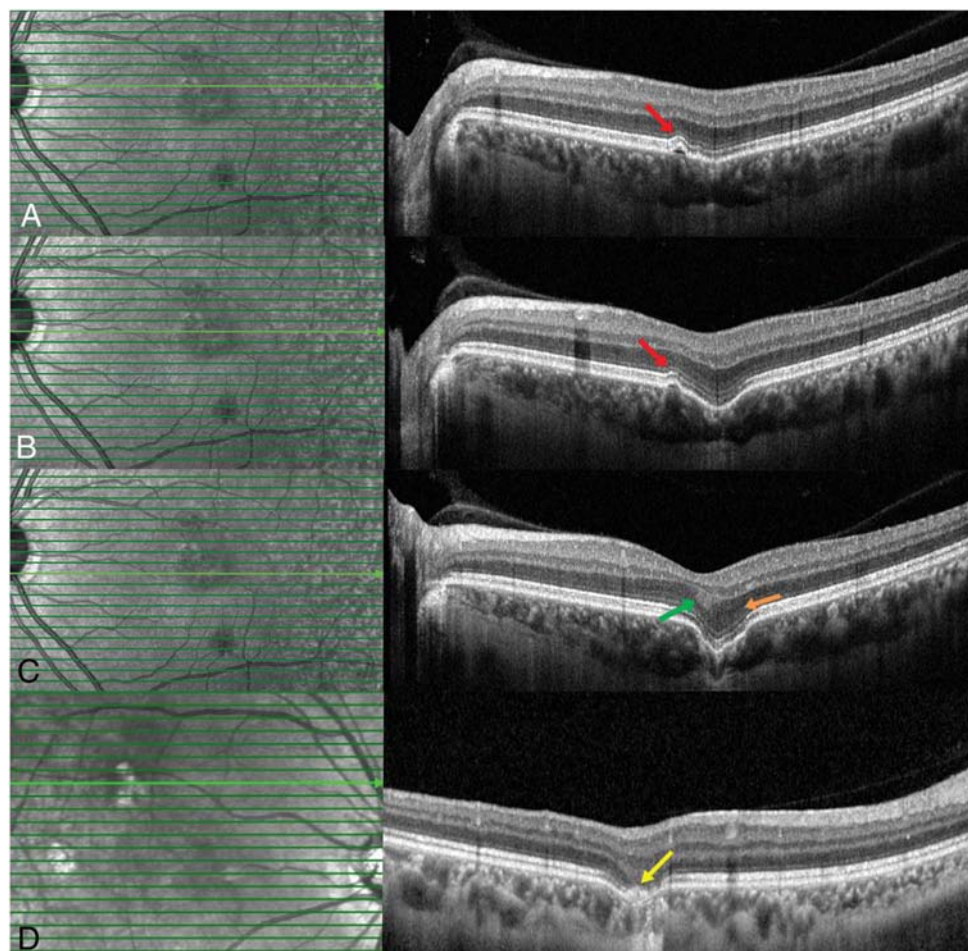
All statistical analyses were performed using Python (v3.11) with the statsmodels and scipy libraries. Two-sided $P < 0.05$ was considered significant.

Results

Overall Detection and Demographics

Among 19,048 individuals (13,793 men and 5,255 women) who underwent OCT-based screening in 2024, FCE was identified in 192 participants—0.98% in men and 1.08% in women—yielding an overall prevalence of 1.0%. Prevalence was highest in individuals aged 30 to 39 years (1.40%), followed by 1.00% in those aged 40 to 49, 0.87% in those aged 50 to 59, and 0.75% in individuals aged 70 to 79. Regarding absolute counts, 47 (24.5%) of affected

Fig. 3. Representative en face and B-scan images illustrating morphologic findings associated with FCE. Each row displays an en face OCT image (left) and the corresponding horizontal B-scan (right) from serial sections through a single eye. **A.** Omega sign (red arrow), defined as a dome-shaped elevation of the retinal pigment epithelium connected to the FCE margin, forming an omega (Ω)-like contour. **B.** Simultaneous visualization of the omega sign and the corresponding FCE within the same B-scan (red arrow). **C.** OPL-like reflectivity (green arrow) within the ONL, as described by Kumano et al, and ONL thickening (orange arrow), as described by Inanc et al. **D.** SHRM is noted within the lesion (yellow arrow).



individuals were in their 30s, 110 (57.3%) in their 40s, 34 (17.7%) in their 50s, and only 1 (0.5%) was in their 70s. No FCE cases were observed in individuals younger than 30 or older than 80 years (Table 1).

The mean age of individuals with FCE was 44.1 ± 6.6 years for men and 43.1 ± 6.1 years for women ($P = 0.344$). Among the 192 individuals, 9 (4.7%) had diabetes mellitus, 17 (8.9%) had hypertension, and 39 (20.3%) had dyslipidemia. In addition, 11 individuals

(5.7%) had two comorbidities and 2 (1.0%) had all three.

Comparison of Demographic, Systemic, and Ocular Features by Fundus Visibility

Table 2 summarizes the demographic, systemic, and ocular characteristics of the fundus-visible group ($n = 128$) and the fundus-invisible group ($n = 124$). Fundus

Table 1. Prevalence of FCE by Age Group and Sex in 19,048 Adults Undergoing OCT-Based Health Screening

Age Groups (years)	Total (N)			Individuals With FCE (N)			Prevalence (%)		
	Males	Females	Total	Males	Females	Total	Males	Females	Total
10–20	0	1	1	0	0	0	0.0	0.0	0.0
20–29	152	67	219	0	0	0	0.0	0.0	0.0
30–39	2,099	1,256	3,355	31	16	47	1.5	1.3	1.4
40–49	8,205	2,856	11,061	78	32	110	1.0	1.1	1.0
50–59	3,146	782	3,928	25	9	34	0.8	1.2	0.9
60–69	142	197	339	0	0	0	0.0	0.0	0.0
70–79	44	89	133	1	0	1	2.3	0.0	0.8
≥80	5	7	12	0	0	0	0.0	0.0	0.0
Total	13,793	5,255	19,048	135	57	192	1.0	1.1	1.0

Table 2. Comparison of Demographic, Systemic, and Ocular Characteristics Between Fundus-Invisible and Fundus-Visible Focal Choroidal Excavations

	Fundus-Invisible FCE (N = 124)	Fundus-Visible FCE (N = 128)	P
Demographic characteristics and systemic comorbidities			
Age (years; mean $\pm$ SD)	45.0 $\pm$ 5.9	43.2 $\pm$ 6.2	0.030*
Sex (M: F; N [%])	83 (66.9):41(33.1)	92 (71.9):36 (28.1)	0.455*
Diabetes (N [%])	9 (7.3)	7 (5.5)	0.613*
HbA1c (%; median [Q1–Q3])	5.5 [5.30–5.70]	5.5 [5.40–5.68]	0.871*
Hypertension (N [%])	12 (9.7)	12 (9.4)	0.935*
Systolic BP (mmHg; median [Q1–Q3])	106 [98.0–115.8]	109 [100.0–117.0]	0.494*
Dyslipidemia (N [%])	32 (25.8)	23(18.0)	0.146*
Total cholesterol (mg/dL; mean $\pm$ SD)	195.1 $\pm$ 30.1	199.0 $\pm$ 36.7	0.365*
Ocular characteristics			
Laterality (OD: OS; N [%])	62 (50.0):62 (50.0)	72 (56.3):56 (43.8)	0.345*
VA (logMAR [mean $\pm$ SD])	0.05 $\pm$ 0.12	0.07 $\pm$ 0.13	0.185*
IOP (mmHg [mean $\pm$ SD])	13.7 $\pm$ 3.2	14.4 $\pm$ 2.9	0.099*
Location of FCE			
Foveal location category (N [%]) (foveal*:parafoveal: perifoveal*:extrafoveal*)	11 (8.9):57 (46.0):47 (37.9):9 (7.3)	46 (35.9):59 (46.1):21 (16.4):2 (1.6)	<0.001†
Adjusted residual of foveal*, perifoveal*, and extrafoveal location*	–5.1, +3.8, and +2.2‡	+5.1, –3.8, and –2.2‡	
ETDRS grid sector (N [%]) (C*: I1: I2*: N1: N2: S1: S2: T1: T2: E1: EN: ET*)	10 (8.1):13 (10.5):9 (7.3):14(11.3):6 (4.8):25 (20.2):6 (4.8):16(12.9):16 (12.9):3 (2.4):1 (0.8):5 (4.0)	49 (38.3):7 (5.5):13 (10.2):8 (6.3):0 (0):2 (1.6):0 (0):10 (7.8):2 (1.6):16 (12.5):2 (1.6):19 (14.8)	<0.001†
Adjusted residual of C*, I2*, and ET*	–5.7, +2.2, and +2.3‡	+5.7, –2.2, and –2.3‡	
Distance from fovea (μ m; median [Q1–Q3])	1,385.0 [796.0–2,233.0]	611.5 [340.5–1098.5]	<0.001§
Morphometric characteristics			
Horizontal diameter (μ m; median [Q1–Q3])	518.0 [387.0–672.0]	681.0 [428.3–946.5]	<0.001§
Depth (μ m; median [Q1–Q3])	45.0 [33.0–60.0]	69.5 [43.8–103.0]	<0.001§
Choroidal thickness (μ m; median [Q1–Q3])	273.0 [215.0–358.0]	285.5 [219.0–360.0]	0.681§
Slope steepness (gradual:steep)	71 (57.3):53 (42.7)	48 (37.5):80 (62.5)	0.002†
Floor shape (“U”：“V”：“W”; N [%])	36 (29.0):84 (67.7):4 (3.2)	37 (28.9):82 (64.1):10 (7.8)	0.276†
ONL thickening (no:yes; N [%])	85 (68.5):39 (31.5)	49 (38.3):79 (61.7)	<0.001†
OPL-like hyperreflectivity (no:yes; N [%])	94 (75.8):30 (24.2)	85 (66.4):43 (33.6)	0.100†
Omega-sign (no:yes; N [%])	97 (78.2):27 (21.7)	89 (69.5):39 (30.5)	0.117†
Associated pathology (N [%])			

(continued on next page)

Table 2. (Continued)

	Fundus-Invisible FCE (N = 124)	Fundus-Visible FCE (N = 128)	P
SRF (no;yes; N [%])	120 (96.8); 4 (3.2)	118 (92.2);10 (7.8)	0.172†
Retinoschisis (no;yes; N [%])	124 (100);0 (0)	126 (98.4);2 (1.6)	0.498¶
Adjacent pachyvessels (no;yes; N [%])	36 (29.0);88 (71.0)	24 (18.8);104 (81.3)	0.055†
Unusual choroidal tissue beneath the FCE (no;yes; N [%])	111 (89.5);13 (10.5)	87 (68.0);41 (32.0)	<0.001†
Subretinal hyperreflective material	123 (99.2);1 (0.8)	120 (93.8);8 (6.3)	0.036¶
Affected layer (none*: BM-RPE complex; EZ*: ONL; OPL*: N [%])	102 (82.3);11 (8.9);8 (6.5);3 (2.4);0 (0)	59 (46.1);21 (16.4);38 (29.7);4 (3.1);6 (4.7)	<0.001**
Adjusted residual of none*, EZ*, and OPL*	+6.0, -4.8, and -2.4‡	-6.0, +4.8, and +2.4‡	

*GEEs.

†Pearson chi-square test.

‡Post hoc analysis using adjusted standardized residuals.

\$Mann-Whitney U test.

¶Fisher exact test.

**Fisher exact test with Monte Carlo simulation.

BM-RPE, Bruch's membrane-retinal pigment epithelium; BP, blood pressure; F, female; GEE, generalized estimating equation; HbA1c, hemoglobin A1c; logMAR, logarithm of the minimum angle of resolution; M, male; OD, right eye; OS, left eye; VA, visual acuity.

visibility was assessed for all 252 FCE lesions using color fundus photographs, with intergrader agreement achieved in 97.2% (245/252). Among the 128 eyes with fundus-visible FCEs, 58 (45.3%) exhibited mild to moderate depigmentation visible on fundus photographs. In 63 eyes (49.2%), pigmentary changes were subtle and appreciable only on OCT-guided review of the lesion location. Hyperpigmentary findings were observed in seven eyes (5.5%).

Individuals with visible FCEs were significantly younger than those with invisible lesions (43.2 ± 6.2 vs. 45.0 ± 5.9 years; $P = 0.030$). Sex distribution was similar between groups (71.9% vs. 66.9% male; $P = 0.455$). No significant differences were observed in systemic comorbidities, including diabetes mellitus (5.5% vs. 7.3%), hypertension (9.4% vs. 9.7%), or dyslipidemia (18.0% vs. 25.8%). Laboratory parameters, including hemoglobin A1c (median 5.5% in both), systolic blood pressure (109 vs. 106 mmHg), and total cholesterol (199.0 vs. 195.1 mg/dL), also did not differ meaningfully.

Focal choroidal excavation was unilateral in 175 individuals (91.1%) and bilateral in 17 (8.9%). Among 209 affected eyes, 85.6% had a single lesion, and 14.4% had multiple lesions. Laterality, BCVA, and IOP showed no significant intergroup differences. The mean BCVA was 0.07 ± 0.13 logarithm of the minimum angle of resolution (approximately 20/23 in Snellen) in the visible group and 0.05 ± 0.12 in the invisible group (approximately 20/22.5 in Snellen); the mean IOP was 14.4 ± 2.9 mmHg and 13.7 ± 3.2 mmHg, respectively (Table 2).

Location and Topographic Distribution

Fundus-visible lesions were most frequently located in the foveal (35.9%) and parafoveal (46.1%) regions, while invisible lesions were predominantly found in the parafoveal (46.0%) and perifoveal (37.9%) zones. Foveal involvement was significantly more common in the visible group, whereas perifoveal and extrafoveal locations were more frequent in the invisible group ($P < 0.001$). The median distance from the foveal center to the nadir of the lesion was significantly shorter in the visible group ($611.5 \mu\text{m}$ [interquartile range, 340.5–1098.5]) than in the invisible group ($1385.0 \mu\text{m}$ [796.0–2233.0]; $P < 0.001$).

Based on the early treatment diabetic retinopathy study grid, visible lesions were most commonly located in the central subfield (38.3%), whereas invisible lesions were dispersed across peripheral sectors, particularly in the inferior outer (I2) and extrafoveal temporal regions ($P < 0.001$). Post hoc analysis confirmed that C-sector involvement was

more common in the visible group, while I2 and extrafoveal temporal locations predominated in the invisible group (Figure 4).

Morphologic and Structural Features

Fundus-visible FCEs exhibited significantly larger median horizontal diameter (681.0 vs. 518.0 μm) and greater depth (69.5 vs. 45.0 μm) than invisible lesions (both $P < 0.001$). Steep slopes were more frequent in the visible group (62.5% vs. 42.7%; $P = 0.002$). Choroidal thickness and the distribution of base configurations (U-, V-, and W-types) did not differ significantly. Outer nuclear layer thickening was significantly more prevalent in visible lesions (61.7% vs. 31.5%; $P < 0.001$). By contrast, OPL-like hyperreflectivity and the omega sign showed no significant intergroup differences (Figure 5).

Associated Retinal and Choroidal Findings

Subretinal fluid was observed in both groups and was numerically more frequent in the visible group (7.8% vs. 3.2%), although the difference was not statistically significant. Retinoschisis was observed only in two eyes from the visible group. Adjacent pachyvessels were slightly more frequent in the visible

group (81.3% vs. 71.0%), although the difference was not statistically significant.

Unusual choroidal tissue beneath the excavation was significantly more common in visible lesions (32.0% vs. 10.5%; $P < 0.001$). Subretinal hyperreflective material was observed in 6.3% of visible FCEs and 0.8% of invisible FCEs ($P = 0.04$). Retinal layer involvement also differed significantly ($P < 0.001$), with ellipsoid zone and OPL involvement more frequently observed in visible lesions, while lesions without retinal involvement were more common in the invisible group (Table 2).

Topographic Location and Its Association with Structural Complexity

Lesion topography was associated with distinct patterns of structural abnormalities. When classified by radial distance from the fovea, foveal lesions showed significantly higher rates of unusual choroidal tissue ($P = 0.001$) and ONL thickening ($P < 0.001$) compared with parafoveal, perifoveal, and extrafoveal lesions. OPL hyperreflectivity also differed significantly across zones, with the highest frequency in the parafoveal region ($P < 0.001$). Similarly, when classified by angular location, central lesions exhibited

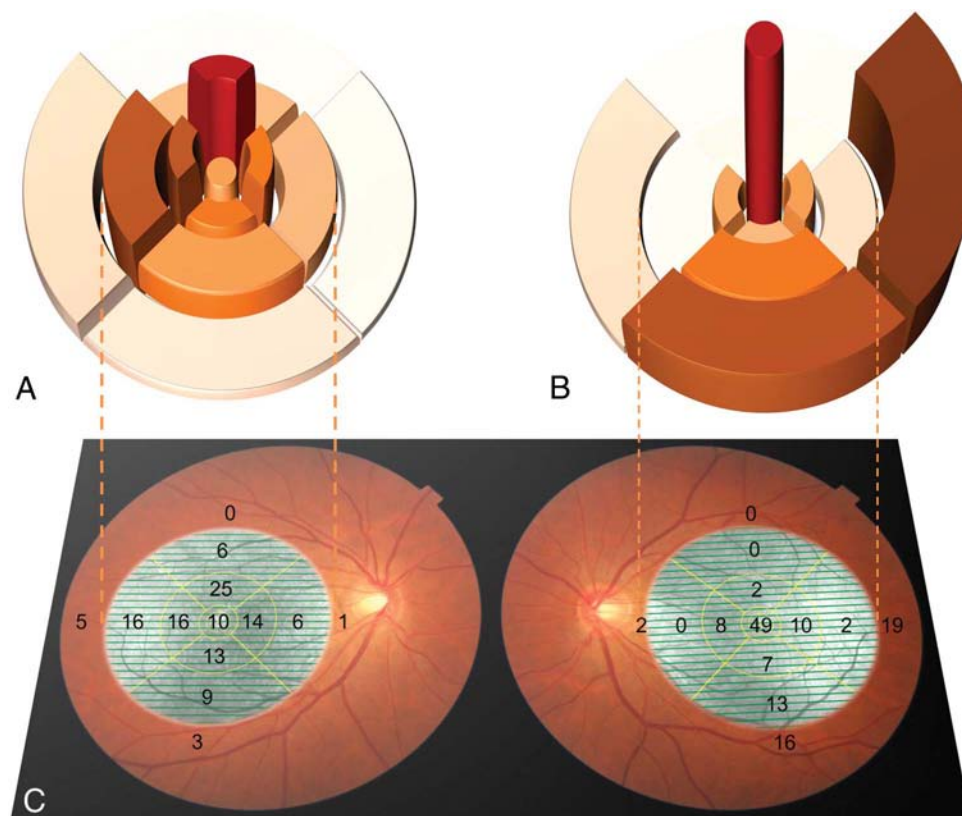
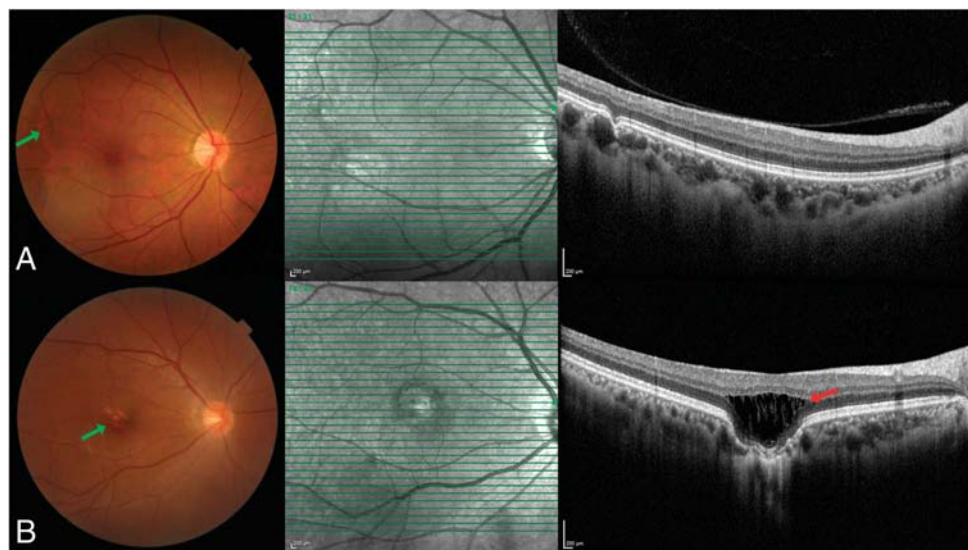


Fig. 4. ETDRS sector-based heatmaps illustrating the topographic distribution of FCE lesions. **A.** Distribution of fundus-invisible FCEs. **B.** Distribution of fundus-visible FCEs. Lesion counts were mapped using the ETDRS grid, which includes the central subfield (C), inner ring sectors (N1: nasal, T1: temporal, S1: superior, I1: inferior; 1,000–1,500 μm from the foveal center), and outer ring sectors (N2: nasal, T2: temporal, S2: superior, I2: inferior; 1,500–3,000 μm from the foveal center). Lesions located beyond 3,000 μm were categorized as extrafoveal. ETDRS, early treatment diabetic retinopathy study.

Fig. 5. Representative cases of fundus-invisible and fundus-visible FCEs, each shown with corresponding fundus photography, en face OCT, and horizontal B-scan. **A.** Fundus-invisible FCE presenting as a small, shallow lesion located away from the foveal center. No visible abnormality is observed on fundus photography (green arrow), and no significant deformation of adjacent retinal or choroidal structures is noted. **B.** Fundus-visible FCE with a large, deep lesion within the central ETDRS subfield. The lesion appears as a slight pigmentary change on the fundus photograph (green arrow) and is associated with structural alterations, including localized retinoschisis observed on the B-scan (red arrow). ETDRS, early treatment diabetic retinopathy study.



a higher prevalence of unusual choroidal tissue ($P = 0.004$) and ONL thickening ($P < 0.001$). By contrast, OPL hyperreflectivity was significantly less frequent in the central region and more common in peripheral zones, particularly in the nasal and temporal sectors ($P = 0.006$). No significant topographic differences were found for SRF, pachyvessels, or SHRM in either classification scheme. Complete results are presented in **Supplemental Digital Content 1** (see **Tables S1 and S2**, <http://links.lww.com/IAE/C828>).

Comparison Between Focal Choroidal Excavation and Matched Controls

After propensity score matching, there were no significant differences in the prevalence of diabetes ($P = 0.942$), hypertension ($P = 0.322$), or dyslipidemia ($P = 0.693$) between individuals with and without FCE. In eye-level comparisons using mixed-effects models, the FCE group demonstrated significantly lower IOP compared with controls ($\beta = -0.611$, $P = 0.026$), and significantly greater choroidal thickness ($\beta = +37.22 \mu\text{m}$, $P < 0.001$). Visual acuity (logarithm of the minimum angle of resolution) did not differ significantly between groups ($P = 0.169$). In addition, generalized estimating equation analysis revealed that the odds of macular degeneration were significantly higher in the FCE group compared with controls ($\beta = 1.044$, $P = 0.002$) (see **Table S3, Supplemental Digital Content 1**, <http://links.lww.com/IAE/C828>).

Because both IOP and choroidal thickness were significantly different in eyes with FCE, an additional mixed-effects model was constructed to evaluate their

potential association. After adjusting for choroidal thickness, IOP remained significantly lower in the FCE group (adjusted $\beta = -0.685$, $P = 0.014$), while choroidal thickness itself showed a marginal positive association with IOP ($\beta = 0.002$ per μm , $P = 0.071$).

Discussion

In this large screening cohort of 19,048 individuals, we identified 192 participants with FCE, involving 209 eyes and 252 lesions. This yielded an estimated prevalence of approximately 1.0%, making it one of the largest studies to date evaluating FCE in a general adult population. By applying OCT to all participants, we captured a wide range of lesions, including those that were subclinical or fundus-invisible, which may otherwise go undetected. In this cohort, the prevalence of FCE was highest among participants in their 30s and decreased progressively in older age groups. This trend may partly reflect the smaller number of participants in the higher age strata (Table 1), which could reduce the statistical likelihood of detecting FCE in those groups. Another plausible explanation is that FCE represents a congenital or early-onset structural anomaly that remains morphologically stable over time. The absence of an age-related increase in prevalence may support this interpretation, and limited short-term follow-up data suggest minimal morphologic progression in many FCEs.¹⁹

Separately, FCE has been reported in association with the pachychoroid spectrum. Chung et al¹⁶ described characteristic pachychoroid features—such

as choroidal thickening and pachyvessels—in eyes with FCE. Azuma et al²⁰ further demonstrated that patients with FCE or pachychoroid pigment epitheliopathy were significantly younger than those with central serous chorioretinopathy or pachychoroid neovascuopathy. These findings suggest that pachychoroid-related FCEs may also occur preferentially in younger adults, supporting an earlier onset rather than age-dependent accumulation, although structural remodeling later in life cannot be excluded. These findings were further supported by our PS-matched analysis, which demonstrated that eyes with FCE had significantly greater choroidal thickness compared with controls.

This structural characteristic reinforces the notion that FCE may be part of the pachychoroid spectrum, particularly in younger individuals with increased choroidal volume. The FCE group also showed a higher prevalence of macular degeneration compared with controls, which may indicate a potential link between FCE and early or subclinical macular changes. However, we note that grading was based on the International Classification of Age-Related Maculopathy and Age-Related Macular Degeneration, a system originally developed for fundus photography that does not incorporate OCT-based criteria.

Visible FCEs exhibited distinct structural features compared with invisible ones: They were more frequently located in the foveal center, tended to be deeper and wider, and were often associated with ONL thickening and abnormal hyperreflective tissue beneath the excavation. By contrast, fundus-invisible FCEs were generally shallower and more morphologically stable, with fewer adjacent retinal changes. These features, along with their detection predominantly in young individuals and occasional multifocal presentation, may be more compatible with a congenital origin in at least a subset of cases.^{1,7} However, the developmental course of such lesions remains uncertain.

Longitudinal studies have shown that some FCEs undergo progressive morphologic changes over time, including conforming-to-nonconforming transitions, emergence of SRF, and development of CNV.^{8–10} For instance, Zheng-Yu et al.¹⁰ documented deepening and widening of lesions, as well as CNV formation, during multiyear follow-up. Docherty et al⁸ described configuration changes in FCE associated with the onset and resolution of central serous chorioretinopathy. Kuroda et al⁹ identified an association between nonconforming FCE and age-related macular degeneration, suggesting that such lesions may reflect early or evolving pathologic states.

Consistent with these reports, we found that fundus-visible FCEs more frequently exhibited features sug-

gestive of structural remodeling, including ONL thickening, ellipsoid zone/OPL disruption, and SHRM. Subretinal fluid and retinoschisis were also observed more often in visible lesions, although the difference in SRF prevalence was not statistically significant. These alterations resemble patterns previously reported in FCEs associated with central serous chorioretinopathy and CNV, which are known to exhibit greater depth, choroidal thinning, and perilesional changes.^{9,11}

In addition, lesions in the foveal and central zones were significantly more likely to exhibit morphologic alterations, including unusual choroidal tissue and ONL thickening, compared with those in peripheral locations (see **Tables S1 and S2, Supplemental Digital Content 1**, <http://links.lww.com/IAE/C828>). This spatial trend parallels the structural complexity observed in fundus-visible FCEs, which were more likely to be centrally located and to demonstrate ONL thickening, SHRM, and increased lesion size. These findings suggest that centrally located FCEs may be subject to greater mechanical or metabolic stress, potentially increasing the likelihood of associated structural remodeling.

While our study design is cross-sectional and therefore cannot establish temporal progression, the structural complexity observed in fundus-visible FCEs closely mirrors the OCT features described in longitudinal series where lesions evolved into pathologic states. These parallels lend credence to the idea that some fundus-visible FCEs may represent lesions at increased risk of future transformation. Although causality cannot be inferred, these findings support the hypothesis that certain FCEs—particularly those with additional structural abnormalities—may warrant closer clinical observation.

In our study, fundus-visible FCEs were more frequently associated with ONL thickening, SHRM, and outer retinal layer disruption. These features suggest that visible lesions may represent morphologically active or structurally unstable forms of FCE. The use of cube scan OCT in a large screening cohort allowed us to capture a broad spectrum of lesions, including subtle or asymptomatic cases. Our findings support the potential utility of fundus visibility as a surrogate marker to guide selective OCT use, particularly in population-based settings where routine OCT is limited.

Although the present classification was derived from OCT-guided assessment, it provides a practical framework for linking fundusoscopic appearance with structural severity. Our findings do not suggest that fundus photographs alone can detect all FCEs; indeed, nearly half (49.2%) of the visible lesions were

appreciable only with OCT-guided localization. Nevertheless, the subset of lesions that were clearly visible on fundus photography demonstrated a higher prevalence of structural abnormalities, supporting the notion that such visible lesions may warrant targeted OCT evaluation in screening settings.

Despite their distinct structural features, fundus-visible FCEs are not always apparent on fundus photography. Rather than presenting as discrete lesions, they often manifest as subtle pigmentary or contour irregularities that may be overlooked during routine examinations. Many were detected when OCT-confirmed lesion locations were used to guide fundus image review, underscoring the limitations of fundus photography alone. This finding reinforces the importance of OCT for identifying clinically inconspicuous FCEs, particularly in younger individuals. The greater visibility of FCEs in younger eyes may be attributed to factors such as higher retinal pigmentation and clearer ocular media. Greater clinical awareness of these limitations may prompt earlier OCT evaluation and support longitudinal monitoring when subtle abnormalities are observed.

This visibility-based classification—while primarily descriptive—offers a practical framework that integrates structural OCT features with funduscopy appearance. The visible lesions correlated strongly with morphologic characteristics such as excavation depth, slope steepness, and lesion width, rather than with age or BCVA. Our study emphasizes that fundus-visible lesions may need OCT imaging even in asymptomatic younger individuals, which may help stratify FCE subtypes and guide appropriate diagnostic follow-up, although its role in clinical decision-making remains to be validated through longitudinal research.

A key strength of our study is the large, population-based cohort, which enabled robust prevalence estimates and characterization of FCE morphology across all ages. By screening individuals—particularly younger adults with good vision—who do not routinely undergo eye examinations that include OCT, we were able to identify subclinical lesions. Access to comprehensive systemic health data also allowed exploratory analyses of nonocular associations. The peak prevalence in the 30s, followed by a gradual age-related decline, may reflect developmental factors or visibility differences. Finally, standardized OCT protocols improved detection of subtle lesions, enhancing the completeness of our findings.

Nevertheless, our study has several limitations. Its cross-sectional nature prevents evaluation of lesion progression or temporal links to retinal pathology. The health screening cohort may not perfectly reflect the general population, risking selection bias. Image

quality—especially in older subjects with media opacity or other retinal diseases—could have affected detection of fundus-invisible FCEs. Finally, classifying subtle fundus changes remains somewhat subjective, which may introduce variability.

In summary, we characterized FCE prevalence and morphology in a large screening cohort. Fundus-visible FCEs exhibited distinct structural alterations that may resemble early macular disease, underscoring that recognizing subtle funduscopy irregularities and performing OCT—even in younger adults with good vision—can enable early identification and monitoring of lesions with high-risk morphologic features.

Key words: focal choroidal excavation, fundus photography, macular diseases, mass screening, optical coherence tomography.

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