



OPEN Changes in retinal vascular geometry after vitrectomy in idiopathic and uveitic epiretinal membrane

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Epiretinal membrane (ERM) can arise idiopathically or secondary to uveitis, each driven by distinct pathophysiological mechanisms. Because ERMs exert tractional forces that distort both the retina and its vasculature, vascular geometry can serve as an indirect marker of the tractional forces acting on the retina. This study aimed to evaluate the associations between postoperative changes in retinal vascular geometry and functional outcomes in patients with idiopathic and uveitic epiretinal membrane (iERM and uERM). A retrospective analysis was performed on 72 eyes (42 iERM, 30 uERM) that underwent pars plana vitrectomy for ERM. Retinal vascular geometric parameters, including arterial and venous angles, branching angles, and tortuosity, were quantitatively measured using conventional retinal fundus photographs. Best-corrected visual acuity (BCVA) and central foveal thickness (CFT) were measured preoperatively and at 1 and 6 months postoperatively. The primary outcome was the comparison of postoperative changes in retinal vascular geometry between iERM and uERM, while the secondary outcome assessed improvements in BCVA, M-score, and CFT, and their correlation with vascular changes. Greater postoperative changes in arterial angle were significantly associated with improvements in BCVA and CFT. The iERM group exhibited more pronounced changes in retinal vascular geometry than the uERM group, particularly in branching venous angles and venous tortuosity. These differences became more evident over time. In conclusion, this study demonstrates that postoperative changes in retinal vascular geometry differ between patients with iERM and uERM, with more significant changes observed in iERM. These findings provide valuable insight into the distinct recovery mechanisms in iERM and uERM, emphasizing the roles of tractional forces and inflammation in shaping postoperative outcomes.

Keywords Epiretinal membrane, Uveitis, Fundus photo, Arterial angle, Venous angle, Tortuosity

Epiretinal membrane (ERM) is characterized by the formation of a fibrocellular membrane on the inner surface of the retina, causing distortion and potential loss of central vision. Idiopathic ERM (iERM), characterized by the absence of any identifiable underlying cause, constitutes a significant proportion of ERM cases. Secondary ERMs, however, develop in association with specific retinal conditions, including retinal vascular diseases, retinal detachment, trauma, and intraocular inflammation¹. Among these, intraocular inflammation-related ERM is notably common, with a prevalence of up to 48% in uveitis patients. ERMs differ in cellular composition and postoperative prognosis depending on their underlying cause^{2–4}.

Previous studies have shown that both the microstructural and macrostructural changes in the retina following ERM surgery are closely linked to functional outcomes^{5–9}. Notably, several studies have focused on changes in retinal vascular geometry, as these alterations are intuitively easier to identify^{5–10}. These studies consistently reported a widening of the divergence angle between major retinal vessels following the release of contracture after ERM removal^{7,11}. However, most studies focus on iERM, leaving limited understanding of how retinal vascular changes may vary with different causes of ERM.

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This study aimed to evaluate postoperative retinal vascular changes in iERM and uveitic ERM (uERM) and assess their impact on functional outcomes. In addition, by comparing retinal vascular changes, we sought to indirectly evaluate the influence of differing contractile forces and inflammation induced by these two types of ERM.

Materials and methods

Participants

This retrospective case-control study involved patients who underwent pars plana vitrectomy (PPV) for ERM treatment at Seoul National University Hospital between January 1, 2012 and December 31, 2020. Seventy-two consecutive patients meeting the study's inclusion and exclusion criteria were included. The study population consisted of subjects 40 years of age or older diagnosed with unilateral ERM before undergoing vitrectomy. This study was approved by the Institutional Review Board of Seoul National University Hospital (IRB no. H-2307-020-1445), and the study was conducted in accordance with the tenets of the Declaration of Helsinki. Owing to the retrospective design of the study and the use of de-identified patient information, the need for written informed consent was waived by the Institutional Review Board of Seoul National University Hospital.

The ERM was diagnosed from the clinical findings of a dilated fundus examination and spectral domain optical coherence tomography (SD-OCT). ERM was defined as semitranslucent fibrocellular tissue on the inner surface of the retina proliferating along the internal limiting membrane (ILM). Patients were classified into two groups depending on their association with uveitis. Those treated for active inflammation due to anterior or intermediate uveitis lasting more than one year, and who developed ERM during or after treatment, comprised the uERM group. Idiopathic ERM (iERM) was defined as the absence of other comorbidities known to be triggers, including uveitis. The exclusion criteria were as follows: (1) a secondary ERM caused by retinal diseases other than uveitis (e.g., retinal vascular disease, diabetic retinopathy, retinal break, and retinal detachment), (2) presence of any other macular/retinal comorbidity that could affect visual acuity, (3) high myopia of ≤ -6 diopters¹²(4) glaucoma, and (5) history of previous vitreoretinal surgery or trauma. Patients with media opacities that could interfere with detailed image analysis were also excluded.

Ophthalmic examinations

All subjects underwent a comprehensive evaluation including best-corrected visual acuity (BCVA), dilated fundus examination, color fundus photography (TRC-501A, Topcon Inc., Tokyo, Japan), and SD-OCT (Cirrus 5000, Carl Zeiss Meditec, Germany) preoperatively and at 1 and 6 months postoperatively. Metamorphopsia was assessed using the M-chart (Inami Co, Tokyo, Japan), and the average horizontal and vertical scores were used for analysis. Ultra-widefield fluorescein angiography (Optos 200Tx; Optos PLC, Dunfermline, UK) were performed within one month prior to PPV to confirm inflammation not identified in the photographs, and the presence of macular leakage was evaluated.

Surgical procedure

A three-port standard PPV was performed using a 25-gauge vitrectomy system - EVA (Dutch Ophthalmic Research Center, Inc, Zuidland, The Netherlands) - with one step scleral tunnel incision. After core vitrectomy, ERM peeling was conducted using end-gripping forceps (Alcon Laboratories Inc). In most cases, curvilinear laminorrhexis of the ILM, with a radius of approximately 2-disc diameter at the foveal center, was performed using end-grip forceps with the assistance of 0.03% indocyanine green staining. Combined cataract surgery was conducted in subjects aged 50 years older.

Evaluation of the retinal vascular geometry

All parameters were evaluated by an independent masked retina specialist (CHL). To measure the diverging angle between the supratemporal and the infratemporal major retinal vessels, we used ImageJ software (ImageJ, version 1.53u, National Institutes of Health, Bethesda, MD, USA) and methods from previous studies⁸. The retinal artery angle and retinal vein angle were measured as follows: First, we measured the distance between the center of the optic nerve head (ONH) and the fovea and drew a circle with a radius corresponding to the distance between the ONH and the fovea; second, we determined the intersection of the drawn circle with the vessels of the superior and inferior arcades and calculated the angle between this intersection and the ONH. The angles of the retinal artery (branching arterial angle) and vein (branching venous angle) bifurcations were measured at the angle of the first bifurcation in the main arcade. To account for potential variability between superior and inferior arcades, the average of the upper and lower branch angles was used for both arterial and venous measurements. Arterial and venous tortuosity were calculated as the ratio of the actual vessel path length between the first and second bifurcations to the straight path length (Fig. 1)⁵.

OCT image analysis

In all cases, a macular cube B-scan were performed before and after surgery. Quantitative parameters, including central foveal thickness (CFT), ERM thickness, and inner-retinal irregularity index (IRII), were measured¹³. CFT was obtained from the central 1-mm subfield in the macular thickness map. Foveal and maximal ERM thicknesses were manually measured using the software's caliper tool, with averaged values derived from both horizontal and vertical B-scan images¹⁴. Foveal ERM thickness was measured at the site of the foveal depression or, when the foveal pit was obscured, by identifying the area where the outer nuclear layer was thickest and symmetrical. Maximal ERM thickness was determined by measuring the thickest point on each of five 6 mm B-scan images, spaced 0.25 mm apart, selecting the highest value. ERM stage and the presence of an ectopic inner foveal layer were evaluated using methods from previous studies¹⁵.

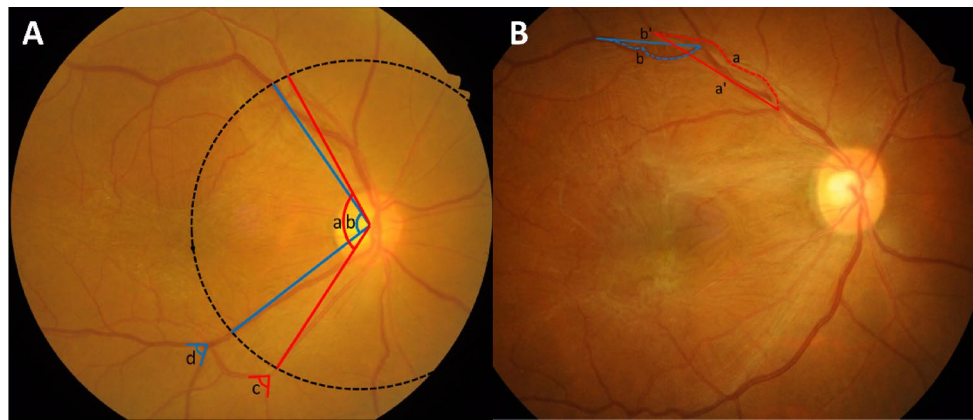


Fig. 1. Evaluation of retinal vascular geometry. All measurements were performed using ImageJ. **(A)** The distance between the optic nerve head (ONH) and the fovea was measured, and a circle (black dotted circle) was drawn with a radius equal to this distance, centered on the ONH. The intersection points where the circle crossed the arteries and veins of the superior and inferior arcade vessels were identified. Angles between these intersection points and the ONH (marked as *a* and *b*) were calculated. The bifurcation angles of retinal arteries and veins (*c* and *d*) were measured at the first bifurcation within the major arcade. **(B)** Retinal arterial and venous tortuosity were calculated as the ratio of the actual vessel length along the vessel path (red and blue dotted lines) between the first and second bifurcation points to the straight-line distance (red and blue solid lines) between the same points. Tortuosity values are expressed as a/a' and b/b' .

Outcome measures

Postoperative measurements of BCVA and M-score were conducted at 1- and 6-month follow-up visits by independent, masked observers. The amount of change in retinal vessel geometry, BCVA, and M-score values between the preoperative visit and the 6-month postoperative follow-up was defined as the delta (Δ) value, respectively (e.g. Δ logMAR BCVA, Δ M-score, Δ CFT).

The primary outcome of this study was the comparison of changes in retinal vascular geometric parameters between the two groups following ERM removal. The secondary outcome was to evaluate of differences in functional and anatomic outcomes between the groups. Further analysis explored the relationship between functional and anatomic outcomes by comparing the Δ values of the two groups. To visually complement the quantitative analysis, we presented vector diagrams showing foveal displacement in representative cases based on fundus photographs (Fig. 2D and H). These diagrams are intended solely for illustrative purposes and were not part of the statistical analysis. To account for potential variability due to stage differences, a subgroup analysis was conducted within the same ERM stage (stage 2). Additionally, an analysis of variance across all ERM stages was conducted to assess whether the observed factors were influenced by ERM stage.

Statistical analysis

BCVA was converted to logarithm of the minimal angle of resolution (logMAR) values. Baseline characteristics and postoperative outcomes following ERM removal were compared between the two groups. Normality of continuous variables was assessed using the Shapiro–Wilk test. Variables that satisfied normality assumptions were analyzed using independent t-tests; otherwise, the Mann–Whitney U test was applied. Results of the normality tests are provided in Supplementary Table S2. Categorical variables were compared using the chi-squared test and Fisher's exact test. Univariable and multivariable linear regression analyses were performed to evaluate associations between clinical factors and changes in BCVA and CFT. Variables with a p -value < 0.15 in univariable analysis were included in the multivariable model selection process using stepwise forward selection. For the BCVA and CFT models, certain baseline parameters—such as baseline BCVA, baseline CFT, and baseline IRII—were excluded from the multivariable analysis due to their strong correlation with the outcome and potential for overadjustment. All the statistical analyses were performed with the SPSS version 27.0 (IBM, Corp, Armonk, NY) and R Studio (ver. 2024.09.1 + 394). A P value of less than 0.05 considered significant.

Results

Seventy-two eyes from 72 patients with ERM were included in the study. Of these, 42 eyes were classified as iERM and 30 as uERM. Figure 2 shows representative cases from the two groups, with vector field analysis used to visualize vascular changes after surgery¹⁶. Table 1 summarizes the baseline characteristics of the patients. The mean age at the time of surgery was 67.1 years in the iERM group and 61.8 years in the uERM group ($p = 0.014$). Combined phacovitrectomy was more common in the iERM group ($p = 0.043$). The iERM group had a higher prevalence of advanced ERM stages ($p = 0.019$), while the uERM group showed significantly thicker ERM (12.54 vs. 10.77 μm , $p = 0.004$). Macular leakage on FA was more frequently observed in the uERM group ($p < 0.001$). In the uERM group, the most common etiology was idiopathic uveitis (53.3%), followed by Behcet's disease (23.3%). Less common causes included toxocariasis (3.3%), sarcoidosis (3.3%), and other or unknown etiologies (16.7%).

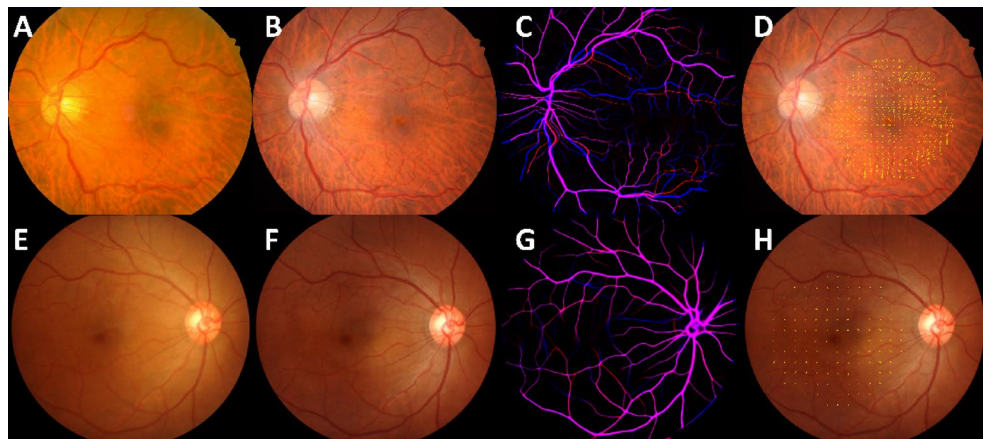


Fig. 2. Representative cases from the idiopathic (iERM) and uveitic (uERM) epiretinal membrane groups. Both cases were classified as Grade 2 ERM based on optical coherence tomography findings. Vector field analysis, using rigid and non-rigid registration techniques with retinal vessel segmentation, quantified and visualized changes after ERM surgery. (A–D) iERM case. (E–H) uERM case. (A,E) Preoperative fundus photographs. (B,F) Corresponding fundus images taken 6 months postoperatively. (C,G) Vessel probability maps showing preoperative vessels in red and postoperative vessels in blue. The overlay highlights vessel location changes, with red indicating preoperative positions and blue indicating postoperative positions. (D,H) Vector field images visualizing retinal displacement. Pixel-wise displacement was calculated by comparing preoperative and postoperative images. Displacement vectors, visualized every 25 pixels, are superimposed on the postoperative fundus images. These are illustrative examples and were not included in the quantitative analysis.

	iERM group (N = 42)	uERM group (N = 30)	p-value
Age, years, mean $\pm$ SD	67.10 $\pm$ 6.54	61.77 $\pm$ 10.02	0.014[#]
Sex, male, N (%)	9 (21.4)	9 (30.0)	0.408
Diabetes mellitus, N (%)	4 (9.5)	4 (13.3)	0.711
Systemic hypertension, N (%)	16 (38.1)	12 (40.0)	0.870
Lens status			
Phakia, N (%)	36 (85.7)	24 (80.0)	0.521
Phacovitrectomy, N (%)	35 (83.3)	18 (62.1)	0.043
IOP, mmhg, mean $\pm$ SD	13.95 $\pm$ 2.44	13.63 $\pm$ 3.12	0.629*
ERM stage, N (%)			0.019
Stage 1	6 (14.3)	10 (33.3)	
Stage 2	20 (47.6)	16 (53.3)	
Stage $\geq$ 3	16 (38.1)	4 (13.3)	
ERM thickness, μ m, mean $\pm$ SD			
Mean thickness	10.77 $\pm$ 1.70	12.54 $\pm$ 3.22	0.017*
Maximum thickness	14.69 $\pm$ 2.82	18.43 $\pm$ 5.02	0.001*
Macular leakage on FA (%)	6 (14.3)	23 (82.1)	<0.001
[†] Uveitis etiology, N (%)			
Idiopathic		16 (53.3)	
Toxocariasis		1 (3.3)	
Sarcoidosis		1 (3.3)	
Behcet's disease		7 (23.3)	
Other/unknown		5 (16.7)	

Table 1. Baseline characteristics of idiopathic and uveitic epiretinal membrane (ERM). Significant values with $p < 0.05$ are in bold. *Mann-whitney U test. #Independent sample t-test. †Etiology available for uERM group only. “Idiopathic” indicates no identifiable systemic or infectious cause despite appropriate evaluation. “Other/Unknown” includes cases with incomplete diagnostic work-up or rare causes not clearly classifiable. Abbreviation: iERM, idiopathic ERM; uERM, uveitic ERM; SD, standard deviation; IOP, intraocular pressure; FA, fluorescein angiography.

	iERM group (N = 42)	uERM group (N = 30)	p-value
BCVA, logMAR			
Baseline	0.30 ± 0.17	0.44 ± 0.27	0.017[#]
Post-op 1 month	0.17 ± 0.17	0.27 ± 0.26	0.097 [*]
Post-op 6 months	0.10 ± 0.18	0.27 ± 0.29	0.004[*]
Δ BCVA	− 0.20 ± 0.19	− 0.17 ± 0.32	0.663 [#]
M-score			
Baseline	0.44 ± 0.43	0.74 ± 0.87	0.602 [*]
Post-op 1 month	0.30 ± 0.45	0.54 ± 0.72	0.376 [*]
Post-op 6 months	0.26 ± 0.46	0.49 ± 0.60	0.154 [*]
Δ M-score	− 0.17 ± 0.53	− 0.24 ± 0.30	0.694 [*]
CFT			
Baseline	415.02 ± 74.31	413.65 ± 85.44	0.536 [*]
Post-op 1 month	394.05 ± 54.40	380.54 ± 75.09	0.394 [#]
Post-op 6 months	383.10 ± 46.74	355.54 ± 62.29	0.042[#]
Δ CFT	− 31.93 ± 54.09	− 58.12 ± 73.69	0.124 [#]
Inner-retinal irregularity index			
Baseline	1.114 ± 0.055	1.113 ± 0.073	0.636 [*]
Post-op 1 month	1.076 ± 0.028	1.081 ± 0.025	0.440 [*]
Post-op 6 months	1.067 ± 0.025	1.077 ± 0.025	0.106 [*]
Δ Inner-retinal irregularity index	− 0.047 ± 0.051	− 0.036 ± 0.083	0.112 [*]

Table 2. Comparison of functional and anatomic outcomes of idiopathic versus uveitic epiretinal membrane (ERM) after vitrectomy. Significant values with $p < 0.05$ are in bold. All results are presented as mean ± standard deviation. Δ, the postoperative change at 6 months from baseline, is defined as [6 months postoperative value - preoperative value]. *Mann-whitney U test. #Independent sample t-test. iERM, idiopathic ERM; uERM, uveitic ERM; SD, standard deviation; logMAR, logarithm of minimal angle of resolution; BCVA, best corrected visual acuity; M-score, metamorphopsia-score; CFT, central foveal thickness.

The postoperative changes in visual function and OCT parameters are presented in Table 2. In both groups, visual function and OCT parameters at 6 months postoperatively showed significant improvement compared to baseline (all $p < 0.05$). However, the degree of improvement did not differ significantly between the two groups for ΔBCVA, ΔM-score, ΔCFT, or Δinner-retinal irregularity index (all $p > 0.05$).

Table 3 shows changes in retinal vascular geometry after ERM removal. Retinal arterial and venous angles tended to increase over time in both groups, while branching arterial and venous angles tended to decrease (Fig. 3A–D). Although both groups exhibited similar trends, changes were more pronounced in the iERM group. Significant differences were observed between the groups in the retinal vein angle (Δ1 month; $p = 0.031$) and branching vein angle (Δ1 month; $p < 0.001$, Δ6 months; $p = 0.001$, respectively). Arterial and venous tortuosity decreased over time in both groups (Fig. 3E, F). At six months postoperatively, changes in arterial and venous tortuosity were significantly greater in the iERM group ($p = 0.006$, and $p < 0.001$, respectively).

A subgroup analysis focusing on stage 2 ERM eyes yielded consistent findings with the overall results. Significant differences were observed between the groups in ERM thickness, changes in branching venous angle, and venous tortuosity at six months postoperatively (Table S1). The analysis of variance conducted without dividing the groups but based on ERM stages revealed that baseline CFT, M-score, and IRII differed significantly depending on the stage (all $p < 0.05$). However, the degree of change in retinal branching vein angle did not vary significantly between stages ($p = 0.263$), suggesting that these changes are influenced by factors beyond ERM stage.

Tables 4 and 5 summarize the univariable and multivariable regression analyses for changes in logMAR BCVA and CFT at 6 months postoperatively. In the univariable analysis, Δ arterial angle was significantly associated with both BCVA and CFT changes ($p < 0.05$), while Δ venous angle showed marginal associations. Other vascular parameters were not significant.

In the multivariable model, Δ arterial angle remained an independent predictor of changes in both BCVA ($p = 0.013$) and CFT ($p = 0.019$). In addition, preoperative pseudophakia ($p = 0.031$) was identified as a significant predictor for BCVA improvement. The model was statistically significant ($F = 5.422$; $p = 0.007$), with an adjusted R^2 of 0.127. For CFT, baseline M-score ($p = 0.036$) and the presence of uERM ($p = 0.049$) were additionally identified as significant predictors. This model demonstrated good explanatory power ($F = 5.593$, $p = 0.002$), with an adjusted R^2 of 0.216.

Discussion

This study compared retinal vascular geometric changes in idiopathic and uveitic ERM patients following vitrectomy. Both groups exhibited similar trends in improvement in visual function (BCVA and M-score) and anatomical parameters (IRII and CFT) after surgery. Additionally, while both groups demonstrated centrifugal

Change in retinal vessel geometry (Δ)	iERM group (N=42)	uERM group (N=30)	p-value
Arterial angle, degree			
Δ 1 month	4.243 ± 3.197	2.886 ± 2.408	0.120*
Δ 6 months	5.655 ± 3.796	4.692 ± 4.769	0.373 [#]
Venous angle, degree			
Δ 1 month	4.250 ± 2.813	2.725 ± 2.611	0.031[#]
Δ 6 months	5.657 ± 3.645	3.991 ± 3.462	0.072 [#]
Branching arterial angle, degree			
Δ 1 month	− 3.080 ± 7.377	− 1.613 ± 4.542	0.276*
Δ 6 months	− 5.200 ± 7.722	− 2.609 ± 5.484	0.146 [#]
Branching venous angle, degree			
Δ 1 month	− 6.441 ± 7.342	− 1.453 ± 3.393	< 0.001[#]
Δ 6 months	− 8.919 ± 8.475	− 2.236 ± 5.155	0.001[#]
Arterial tortuosity, %			
Δ 1 month	− 2.73 ± 4.99	− 1.11 ± 2.36	0.107*
Δ 6 months	− 3.56 ± 5.73	− 1.37 ± 2.40	0.006*
Venous tortuosity, %			
Δ 1 month	− 3.29 ± 2.59	− 0.21 ± 1.66	< 0.001*
Δ 6 months	− 3.42 ± 1.99	− 0.41 ± 1.79	< 0.001[#]

Table 3. Comparison of retinal vessel geometric changes in idiopathic versus uveitic epiretinal membrane (ERM) after vitrectomy. Significant values with $p < 0.05$ are in bold. All results are presented as mean ± standard deviation. Δ, the postoperative change at 6 months from baseline, is defined as [6 months postoperative value - preoperative value]. *Mann-whitney U test. [#]Independent sample t-test. iERM, idiopathic ERM; uERM, uveitic ERM.

improvement in retinal vascular geometry, geometric parameters were significantly more pronounced in the iERM group. Notably, significant differences were observed in the retinal branching vein angle and venous tortuosity, findings that were consistent in subgroup analyses within the same ERM stage.

The tractional force exerted by the ERM on the inner retina pulls retinal vessels toward the macula, causing vessel distortion and displacement^{7,8,11,17}. Previous studies on retinal vascular geometry in ERM have highlighted these structural changes. Chous et al.⁷ demonstrated that widening of the vascular arcade angle after surgery predicts visual improvement. Nagura et al.⁸ reported that eyes with iERM have smaller retinal arterial angles compared to contralateral normal eyes, and larger arterial angles correlate with better BCVA. Miyazawa et al.⁵ found retinal vessel tortuosity to be correlated with visual outcomes after ERM surgery. These findings indicate that relief of tractional forces and restoration of retinal structure after surgery improve not only visual function and anatomical parameters but also vascular geometry. Consistent with previous research, our study showed that greater postoperative changes in arterial angle were associated with improved visual acuity and reduced CFT. This supports the conclusion that retinal vascular geometry plays a pivotal role in both functional and anatomical improvement. In addition, baseline M-score was significantly associated with postoperative CFT reduction in the multivariable analysis, suggesting a potential link between subjective metamorphopsia severity and anatomical recovery. This finding aligns with previous studies^{18,19}.

Morphological changes and the release of tractional forces support the presence of active contractile forces in ERM, with differences in relief degree reflecting the ERM's origin rather than its severity. Subgroup analyses of stage 2 ERM further support this conclusion. While baseline CFT, M-score, and IRII varied across ERM stages, the degree of change in retinal branching vein angle did not differ significantly, suggesting that these changes are influenced by factors beyond ERM stage. According to previous literature, histological differences between iERM and uERM, particularly in cellular composition, likely contribute to these findings^{4,20}. Histologically, iERM contains more Müller glial cells, hyalocytes, and retinal pigment epithelial cells—precursors of myofibroblasts that contribute to higher contractility². In contrast, uERM is rich in inflammatory cells such as lymphocytes, histiocytes, and plasma cells, embedded within a stromal matrix of glial elements and condensed vitreous⁴. These cellular differences likely explain the variations in contractility and postoperative outcomes between the two ERM types.

Changes in vascular geometry were more pronounced in branch retinal vessels compared to major vessels, likely due to branch vessels being closer to the centripetal tractional forces exerted by the ERM on the fovea²¹. Retinal arteries, with their smaller diameter and thicker walls, show greater structural resistance to deformation compared to veins, which are more susceptible to mechanical forces due to their larger diameter and thinner walls^{22–25}. This mechanical susceptibility may explain the greater differences in branching venous angle changes observed between the two groups.

Interestingly, in this study, uERM patients had greater mean and maximum ERM thickness compared to iERM patients. Previous research has shown that ERM thickness in uveitis patients increases over time due to continuous cytokine production, even in the absence of visible inflammation^{14,26}. The accumulation of

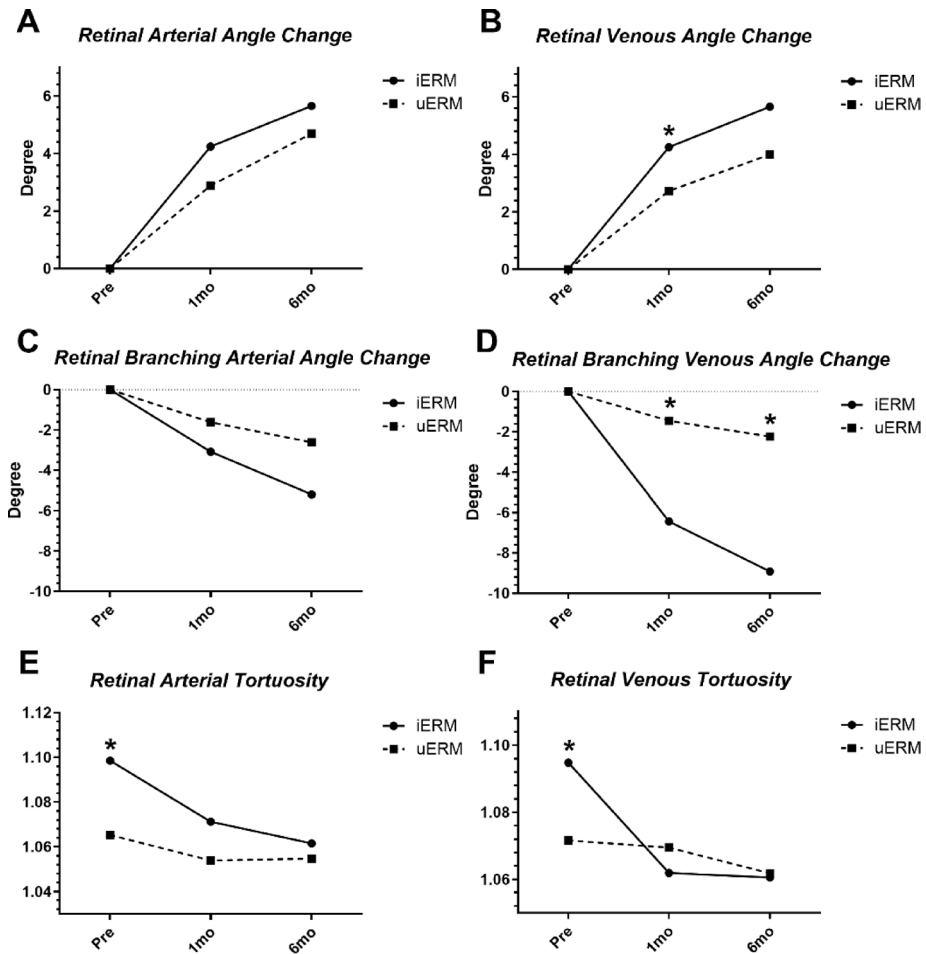


Fig. 3. Postoperative changes in retinal vascular geometry after ERM surgery. (A–D) Graphs showing changes in retinal arterial and venous angles at 1 and 6 months postoperatively, highlighting differences in the magnitude of change between the iERM and uERM groups. (E,F) Retinal arterial and venous tortuosity were higher in the iERM group preoperatively and showed a greater reduction postoperatively compared to the uERM group. Postoperative retinal arterial and venous angles increased over time, with significant differences in venous branch angles between the groups at all time points. Vessel tortuosity (both arterial and venous) decreased in both groups, with the iERM group showing a significantly greater reduction at 6 months.

inflammatory materials and cytokines explains the observed differences in ERM thickness between uERM and iERM. Although uERM patients demonstrated greater improvement in CFT post-surgery, their improvements in BCVA, M-score, and IRII were less pronounced than those of the iERM group. This suggests that chronic inflammation, as evidenced by macular leakage on FA, significantly impacts visual recovery in uERM patients. This can be explained by the weaker contractile forces in uERM, primarily formed by inflammatory cells, which result in less macular distortion and, consequently, smaller changes in retinal vascular geometry after surgery. Additionally, chronic inflammation in uERM, which limits functional recovery, further contributes to these differences.

This study has several limitations. First, the retrospective design prevented histological analysis of ERM composition, which could have provided direct insights into cellular differences between iERM and uERM. Second, the relatively short follow-up period may not capture long-term outcomes. Additionally, the small sample size limits the generalizability of the results. Baseline differences between the groups, including age and ERM staging, may also have influenced the findings. Lastly, angular changes in vessel positions were measured using imaging techniques, which could exaggerate changes in veins due to their larger diameter. Thus, differences in vascular geometry between veins and arteries may partially reflect measurement sensitivity rather than physiological differences. Furthermore, we did not include fractal dimension or multifractal analysis, which may offer deeper insights into vascular complexity, due to image quality variability and the retrospective nature of this study. Despite these limitations, this study provides valuable insights into postoperative functional and vascular geometric changes in ERMs of different origins, with subgroup analysis controlling for ERM stage. Future prospective studies incorporating histological analysis and advanced imaging techniques, such as OCTA-based fractal analysis, are needed to address these issues.

Variables	Univariable		Multivariable	
	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
Age	0.000 (– 0.007 to 0.007)	0.974		
Sex: female	– 0.019 (– 0.158 to 0.120)	0.787		
Group: uERM	– 0.029 (– 0.150 to 0.092)	0.635		
Preoperative lens status : Pseudophakia	0.132 (– 0.024 to 0.287)	0.096	0.186 (0.018–0.354)	0.031
Phacovitrectomy	– 0.051 (– 0.191 to 0.090)	0.474		
Baseline BCVA (logMAR) [†]	0.526 (0.291–0.760)	<0.001	–	–
Baseline M-score	0.052 (– 0.059 to 0.163)	0.352		
Baseline CFT	0.000 (0.000–0.001)	0.167		
Baseline IRII	0.634 (– 0.299 to 1.566)	0.180		
ΔArterial angle	0.018 (0.003–0.034)	0.022	0.019 (0.004–0.034)	0.013
ΔVenous angle [‡]	0.017 (– 0.001 to 0.034)	0.068	–	–
ΔBranching arterial angle	– 0.001 (– 0.011 to 0.008)	0.779		
ΔBranching venous angle	0.001 (– 0.007 to 0.010)	0.736		
ΔArterial tortuosity	0.135 (– 1.258 to 1.529)	0.847		
ΔVenous tortuosity [‡]	– 2.186 (– 4.934 to 0.563)	0.117	–	–

Table 4. Univariable and multivariable linear regression analyses for predictors of BCVA change at 6 months after vitrectomy. Significant values with $p < 0.05$ are in bold. Changes in BCVA are defined as [preoperative values – 6 months postoperative values]. Δ, the postoperative change at 6 months from baseline, is defined as [6 months postoperative value – preoperative value]. [†]Baseline BCVA was excluded from the multivariable model due to its strong correlation with the outcome and the risk of overadjustment, despite being statistically significant in univariable analysis. [‡]Variables with $p < 0.15$ in univariable analysis that were included in the multivariable selection process but not retained in the final model. **Multivariable model summary: ** $F = 5.422$, $p = 0.007$; Adjusted $R^2 = 0.127$. BCVA, best-corrected visual acuity; logMAR, logarithm of minimal angle of resolution; CFT, central foveal thickness; M-score, metamorphopsia-score; CI, confidence interval; uERM, uveitic epiretinal membrane; IRII, inner-retinal irregularity index.

Variables	Univariable		Multivariable	
	Coefficient (95% CI)	p-value	Coefficient (95% CI)	p-value
Age [‡]	– 1.446 (– 3.408 to 0.515)	0.146	–	–
Sex: female	22.889 (– 12.958 to 58.737)	0.207		
Group: uERM	26.187 (– 4.825 to 57.199)	0.097	34.140 (0.188–68.091)	0.049
Preoperative lens status : Pseudophakia	27.509 (– 13.740 to 68.757)	0.188		
Phacovitrectomy [‡]	– 39.067 (– 74.420 to – 3.715)	0.031	–	–
Baseline BCVA (logMAR) ^{††}	105.654 (– 38.653 to – 172.654)	0.002	–	–
Baseline M-score [‡]	40.842 (11.373 to 70.311)	0.008	31.138 (2.047–60.228)	0.036
Baseline CFT ^{††}	0.583 (0.446–0.720)	< 0.001	–	–
Baseline IRII ^{††}	679.415 (498.186–860.643)	< 0.001	–	–
ΔArterial angle	6.281 (2.709–9.852)	0.001	4.767 (0.830–8.704)	0.019
ΔVenous angle [‡]	3.898 (– 0.460 to 8.255)	0.079	–	–
ΔBranching arterial angle	– 1.616 (– 3.889 to 0.658)	0.160		
ΔBranching venous angle	– 0.623 (– 2.662 to 1.415)	0.543		
ΔArterial tortuosity	– 78.357 (– 418.088 to 261.373)	0.646		
ΔVenous tortuosity	– 301.823 (– 989.620 to 385.974)	0.383		

Table 5. Univariable and multivariable linear regression analyses for predictors of CFT change at 6 months after vitrectomy. Significant values with $p < 0.05$ are in bold. Changes in CFT are defined as [preoperative values – 6 months postoperative values]. Δ, the postoperative change at 6 months from baseline, is defined as [6 months postoperative value – preoperative value]. ††Baseline BCVA, baseline CFT, and baseline IRII were excluded from the multivariable model due to their disproportionately strong influence on the outcome and the risk of overadjustment, despite being statistically significant in univariable analysis. ‡Variables with $p < 0.15$ in univariable analysis were included in the multivariable selection process but were not retained in the final model. **Multivariable model summary: ** F = 5.593, $p = 0.002$; Adjusted $R^2 = 0.216$. BCVA, best-corrected visual acuity; logMAR, logarithm of minimal angle of resolution; CFT, central foveal thickness; M-score, metamorphopsia-score; CI, confidence interval; uERM, uveitic epiretinal membrane; IRII, inner-retinal irregularity index.

In conclusion, this study demonstrates that changes in retinal vascular geometry after surgery differ between patients with iERM and uERM, with more pronounced changes observed in iERM. These findings suggest that differences in contractile forces, which cannot be fully revealed by functional outcomes alone, may depend on the etiology of the ERM.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

C.H.L. wrote the manuscript, conducted statistical analysis, and researched data. K.B. designed and supervised the study and edited the manuscript. C.H.L. and K.B. contributed equally as co-first authors. S.W.C., E.K.L., C.K.Y., U.C.P., and K.H.P. reviewed the manuscript. S.G. and S.J.P. analyzed representative cases and created vector field images.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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