

Combined versus Sequential Surgery in Lamellar Macular Holes: A Multicenter Observational Study

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Purpose: To compare 1-year best-corrected visual acuity (BCVA) after pars plana vitrectomy (PPV) for lamellar macular hole (LMH) between combined phacovitrectomy and sequential strategies, and to explore factors associated with postoperative visual outcome.

Methods: Multicenter observational study of adults with optical coherence tomography (OCT)-confirmed LMH undergoing PPV. Surgical sequence was classified as combined surgery or sequential surgery (PPV→phacoemulsification, PPV in pseudophakic eyes, or PPV without subsequent cataract extraction). LMHs were classified as tractional, mixed, or degenerative based on OCT criteria. BCVA (logMAR) was recorded preoperatively and at 1 year. Ceiling effect was defined as achieving 1-year BCVA ≤ 0.22 logMAR. Independent predictors of 1-year BCVA were assessed using a linear mixed-effects model with a random intercept for patient.

Results: A total of 175 eyes from 167 patients were included; 1-year BCVA was available for 126 eyes (72.0%), whereas 49 eyes (28.0%) had missing 1-year BCVA. Among eyes with recorded 1-year BCVA, no statistically significant differences were detected between combined and sequential surgery (0.2 [0.1–0.3] vs 0.2 [0.1–0.3]; $p = 0.939$) or among LMH subtypes. Overall, BCVA improved from 0.4 (IQR 0.3–0.5) to 0.2 (0.1–0.3) at 1 year. In ceiling-effect analysis, baseline BCVA ($p = 0.013$) and the presence of isolated epiretinal membrane ($p = 0.032$) were associated with achieving BCVA ≤ 0.22 logMAR. In the mixed-effects model, baseline BCVA was the only independent predictor of 1-year BCVA ($\beta = 0.60$; 95% CI 0.32–0.89; $p < 0.001$).

Conclusion: PPV for LMH was associated with visual improvement at 1 year, and the study did not detect statistically significant differences in final BCVA between combined and sequential strategies or among LMH subtypes. Baseline BCVA was the main determinant of 1-year outcomes, supporting individualized selection of surgical sequence based on lens status and shared patient–surgeon preferences.

Plain Language Summary: Lamellar macular hole is a condition that affects the center of the retina. It can make vision blurred, distorted, or less clear for everyday tasks such as reading.

Many people who need surgery for lamellar macular hole also have cataract. Surgeons can treat both problems during the same operation, or they can do cataract surgery later. In daily practice, patients and surgeons often need to decide which approach to choose.

In this study, we looked at people treated in four Spanish hospitals. We compared vision at 1 year after vitrectomy in those who had combined surgery and those who had sequential surgery. We also studied which factors were linked to better vision after surgery.



Overall, vision improved at 1 year after surgery. We did not detect clear differences in vision at 1 year between combined and sequential surgery. People who had better vision before surgery were more likely to have better vision after surgery. Patients with an isolated epiretinal membrane on OCT were also more likely to achieve better visual outcomes.

These findings suggest that both surgical approaches can be reasonable. The best choice may depend on the person's lens status, symptoms, and discussion with the surgeon.

Keywords: lamellar macular hole, pars plana vitrectomy, phacovitrectomy, combined surgery, sequential surgery, epiretinal membrane, visual outcomes, optical coherence tomography, OCT

Introduction

Lamellar macular holes (LMHs) are vitreomacular interface disorders that typically cause an insidious and slowly progressive impairment of central visual function. Their etiology, pathogenesis, and optimal management remain incompletely understood. At present, surgery is the only therapeutic option; however, it is invasive, technically demanding, and not free of potentially relevant complications. In daily vitreoretinal practice, one of the most frequent decisions is whether cataract surgery should be performed simultaneously with vitrectomy or at a separate stage. This question has been investigated in other macular disorders, including full-thickness macular holes and epiretinal membranes, but not specifically in LMHs.^{1–4}

LMH is an uncommon condition, with a reported prevalence ranging from 0.1% to 0.9% worldwide^{5–8} and approximately 0.1% in Spain.⁸ This low prevalence makes it difficult to generate robust clinical evidence, particularly for surgical questions. Consequently, much of the available literature consists of retrospective series and heterogeneous cohorts, which limits the strength and generalizability of current evidence.⁹

In addition, LMHs are not a uniform entity. They comprise different morphological subtypes with distinct structural and functional features. When classified into tractional, mixed, and degenerative forms, degenerative LMHs are the least frequent and have been associated with poorer postoperative visual outcomes.^{10,11} This clinical heterogeneity further limits direct extrapolation from studies performed in other vitreoretinal diseases and underscores the need for LMH-specific data.

The clinical relevance of this question is further increased by the demographic profile of affected patients. Population-based studies show that LMHs become more common with age, with a mean age at diagnosis of approximately 76 years.⁶ At this stage of life, cataract is frequently present, making the choice between combined phacovitrectomy and a sequential strategy a common and practical issue in routine care. At the same time, interpretation of postoperative visual outcomes may be confounded by lens status, because part of the observed visual improvement after combined surgery may be attributable to cataract extraction rather than to LMH repair itself.

Generating prospective controlled evidence in this field is challenging. Beyond the low prevalence of LMH, surgical decision-making is strongly influenced by baseline lens status, age, symptoms, and surgeon judgment, which makes strict protocol-driven comparison difficult in routine clinical practice. For this reason, large contemporary multicenter observational cohorts may provide clinically useful information to address this unresolved question.

Accordingly, the present study aimed to compare best-corrected visual acuity (BCVA) at 1 year after vitrectomy across different surgical sequences for LMH, using a multicenter cohort designed to reflect real-world practice. Secondary objectives were: (1) to analyze BCVA gain in order to estimate the functional contribution of each surgical component; (2) to explore factors associated with final visual outcome through multivariable and ceiling-effect analyses; and (3) to assess whether surgical sequence influences visual prognosis across different LMH subtypes and surgical modalities.

Materials and Methods

Study Design

A multicenter observational study was conducted across four Spanish hospitals: the University Hospital of Navarra, Reina Sofía University Hospital of Murcia, General University Hospital of Castellón, and Bellvitge University Hospital (Barcelona). Given the low prevalence of lamellar macular hole (LMH), potentially eligible cases were recorded as they occurred in order to maximize sample size. However, the present analysis was based on retrospective review of surgical records, medical charts, and OCT images. The principal investigator did not participate in treatment decisions or surgical management. Surgical sequence was determined according to routine clinical practice at each center and surgeon preference, without protocol-driven allocation or randomization. Investigators from each center provided anonymized clinical data and OCT images to the principal investigator, who verified compliance with the predefined morphological diagnostic criteria. OCT devices used included the Heidelberg Spectralis with HEYEX software (Navarra and Murcia) and the Triton–Topcon system (Castellón and Bellvitge). The study was approved by the Clinical Research Ethics Committee of Navarra (Protocol v.210605, Patient Information Sheet and Informed Consent Form v.210607) and was conducted in accordance with the Declaration of Helsinki and applicable national and international regulations, including Spanish Biomedical Research Law 14/2007 and the international Guidelines for Ethical Review of Epidemiological Studies (CIOMS, Geneva, 2009). Written informed consent was obtained from all participants. No a priori sample size calculation was performed because this was a multicenter observational study and all eligible consecutive eyes available during the study period were included. Based on the available group sizes (101 eyes in the combined surgery group and 74 in the sequential surgery group), the study had 80% power at a two-sided alpha of 0.05 to detect a between-group difference of 0.150 logMAR units. Smaller differences may therefore have remained undetected.

Inclusion and Exclusion Criteria

Patients aged 18 years or older with a confirmed diagnosis of lamellar macular hole (LMH) on optical coherence tomography (OCT) who underwent pars plana vitrectomy between 2012 and 2024 were included.

Exclusion criteria comprised concomitant ocular diseases that could interfere with central visual function, such as corneal scarring or prior keratoplasty, advanced glaucoma, proliferative diabetic retinopathy, exudative or atrophic age-related macular degeneration, high myopia with macular choroidal atrophy, as well as cases lacking essential information for the planned analyses (eg, missing baseline BCVA) or missing imaging documentation.

Surgical Classification

The surgical procedures were classified into two main categories: combined surgery, consisting of phacovitrectomy performed in a single surgical session, and sequential surgery, in which cataract extraction and vitrectomy were carried out at different times. The sequential group included three subgroups: vitrectomy followed by phacoemulsification, vitrectomy in pseudophakic eyes, and vitrectomy without subsequent cataract surgery. All procedures were performed using 23-gauge pars plana vitrectomy in all participating centers. Because the cohort spans a long period, ancillary surgical steps—including the extent of membrane peeling and the use of intraocular tamponade (air or gas)—were performed at the discretion of the operating surgeon and may have varied over time; however, gauge size was consistent across centers.

Morphological Definition and Subtype Classification

The diagnosis of lamellar macular hole (LMH) was established using optical coherence tomography (OCT) according to previously published morphological criteria.^{12–18} Cases were classified into three subtypes—tractional, mixed, and degenerative—based on foveal structural features observed on OCT. Representative OCT images for each subtype are shown in [Figure 1](#). A detailed description of the diagnostic criteria and the specific morphological characteristics used for each subtype is provided in [Supplementary Table S1](#).

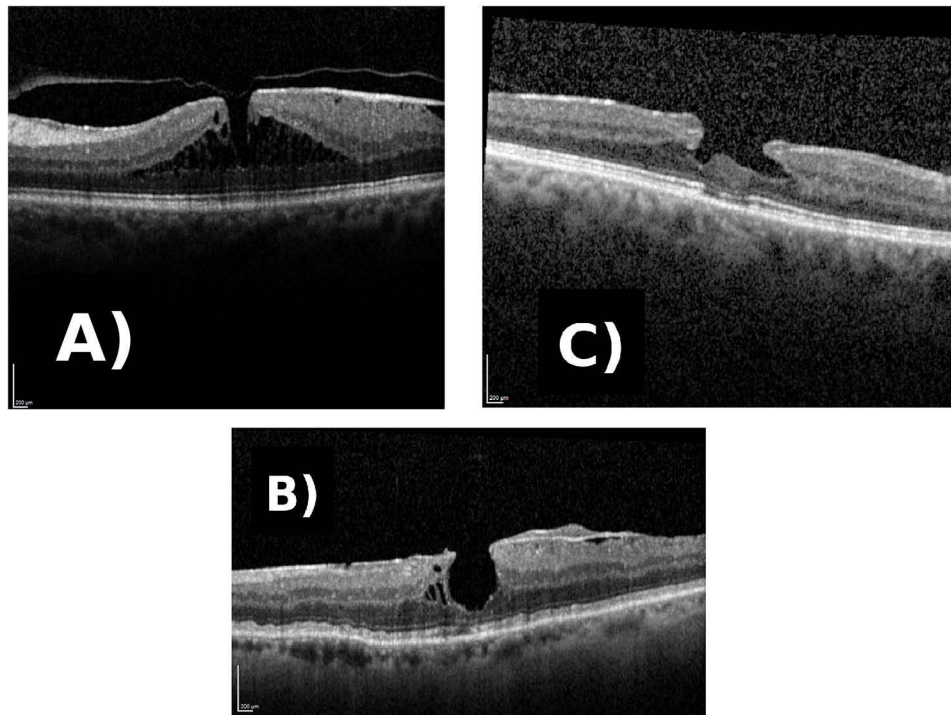


Figure 1 Representative OCT images of lamellar macular hole subtypes. (A) Tractional subtype. (B) Mixed subtype. (C) Degenerative subtype.

Study Variables

Demographic, morphological, and functional variables were collected. Morphological variables included LMH subtype, type of epimacular tissue (epiretinal membrane, ectopic tissue, or both), and crystalline lens status at the time of surgical planning. Lens status was extracted from the clinical record and categorized as clear crystalline lens, cataract, pseudophakia, or nuclear sclerosis, according to the preoperative slit-lamp assessment documented by the treating surgeon. This variable was intended to characterize preoperative lens status in the context of surgical sequence planning. The category of nuclear sclerosis referred to mild age-related lens changes without clinically significant cataract requiring surgery on its own. Functional variables included best-corrected visual acuity (BCVA), recorded in decimal notation and converted to logMAR for analysis, both preoperatively and 1 year after vitrectomy. In the sequential surgery group, BCVA immediately before cataract extraction and 1 month after phacoemulsification was also recorded. Preoperative metamorphopsia and its postoperative course (absence, improvement, or persistence) were additionally documented when available. However, metamorphopsia was not considered a primary outcome because its retrospective documentation was not protocolized across centers and its assessment in routine clinical practice was not sufficiently standardized to support robust comparative analysis.

Statistical Analysis

A descriptive analysis of the cohort's clinical and functional characteristics was performed. Continuous variables were reported as medians and interquartile ranges (IQR), and categorical variables as counts and percentages. Changes in BCVA were assessed using the Wilcoxon signed-rank test for paired data. BCVA at 1 year after vitrectomy was compared across groups using the Mann–Whitney *U*-test for two-group comparisons and the Kruskal–Wallis test for comparisons involving more than two groups. Visual gain ($\Delta\log\text{MAR}$) was calculated as 1-year logMAR minus preoperative logMAR; therefore, more negative values indicate greater visual improvement. Visual gain distributions were displayed using boxplots stratified by surgical modality and LMH subtype. The primary functional outcome was BCVA at 1 year after PPV, selected to capture a more stable postoperative visual status, to reduce cataract-related confounding in sequential cases, and to maximize

comparability across centers. Although follow-up beyond 1 year was available for a subset of eyes, its availability decreased progressively over time; therefore, longer-term data were considered descriptive and were not used as the primary endpoint.

To explore the potential presence of a ceiling effect, achieving a BCVA ≤ 0.22 logMAR at 1 year was considered the outcome. This cutoff was selected based on the distribution of our own 1-year BCVA results. In both the between-group analyses and the intra-eye comparisons, postoperative BCVA values tended to cluster around ~ 0.2 logMAR at 1 year, suggesting a potential upper functional plateau after LMH surgery. We therefore used 0.22 logMAR as a pragmatic threshold close to this observed plateau to define a “high postoperative visual outcome” and to explore clinical factors associated with reaching this ceiling (exploratory analysis). This ceiling-effect analysis was hypothesis-generating and should be interpreted accordingly.

Bivariate analyses were conducted to evaluate associations between this outcome and clinical variables (baseline BCVA, macular morphology, and type of epimacular tissue) using the chi-square or Fisher’s exact tests for categorical variables and the Mann–Whitney *U*-test for continuous variables. To assess independent predictors of final BCVA, a linear mixed-effects model was fitted with 1-year BCVA (logMAR) as the dependent variable, including baseline BCVA, age, lens status at surgical planning, LMH subtype, and surgical modality as fixed effects, and a random intercept for patient to account for within-patient clustering when both eyes contributed data. Full model estimates are provided in [Supplementary Table S3](#).

Potential Sources of Bias

Information bias was mitigated by confirming LMH on OCT and applying prespecified OCT-based morphological and subtype criteria, with centralized image review by the principal investigator. To reduce cataract-related confounding, the primary endpoint was defined at 1 year after PPV; in the PPV→phaco subgroup, most eyes had undergone cataract extraction before the 1-year assessment, thereby limiting the influence of untreated lens opacity on the endpoint. Attrition bias was addressed by treating 1-year BCVA as missing outcome data (available-case approach), reporting outcome availability by surgical modality ([Supplementary Table S2](#)), and interpreting small subgroups with incomplete follow-up cautiously. Because surgical allocation was not randomized and reflected routine clinical practice, residual confounding by indication cannot be fully excluded.

Sensitivity and Exploratory Analyses

A sensitivity analysis was performed excluding the “PPV without phacoemulsification” subgroup because of its small sample size ($n = 5$) and limited availability of the primary 1-year outcome (only two eyes with recorded 1-year BCVA). In addition, eyes with available 1-year BCVA were compared with those lacking this outcome to explore potential attrition bias. This comparison included baseline demographic, functional, morphological, lens-status, and surgical-sequence variables, as well as intermediate postoperative BCVA recorded between 3 and 12 months after PPV. Finally, an exploratory descriptive comparison across participating centers was performed to assess whether baseline LMH subtype distribution, baseline BCVA, and surgical sequence varied across sites.

Missing Data

Owing to the observational design and retrospective extraction of clinical data, some variables were not available for all cases. No data imputation was performed. Descriptive and bivariate analyses were conducted using an available-case approach, with denominators reflecting the number of eyes/patients with recorded information for each specific analysis. The amount of missing data by variable is detailed in the notes to [Table 1](#). For the primary outcome (1-year BCVA), eyes without a recorded 1-year BCVA were treated as missing outcome data and were not included in that specific analysis. In the “PPV without phacoemulsification” subgroup, 1-year follow-up was incomplete (only two eyes completed the 1-year assessment), and findings were interpreted cautiously. The mixed-effects model was fitted using complete-case analysis for the covariates included. The unit of analysis was the eye, consistent with the study design and the clinical endpoint. Because a small number of participants contributed both eyes, within-patient correlation was addressed in the multi-variable analysis by fitting a mixed-effects model with a random intercept for patient.

Table 1 Baseline Characteristics of the Cohort by LMH Subtype (A) and Surgical Modality (B)

Variable	Category	Tractional n (%)	Mixed n (%)	Degenerative n (%)	p (Subtypes)	
(A) By lamellar macular hole (LMH) subtype						
Sex	Male	26 (24.5)	29 (70.7)	18 (66.7)	<0.001	
	Female	80 (75.5)	12 (29.3)	9 (33.3)		
Age (years)	<55	5 (4.7)	1 (2.4)	2 (7.1)	0.882	
	55–65	24 (22.6)	7 (17.1)	5 (17.9)		
	65–75	48 (45.3)	19 (46.3)	11 (39.3)		
	>75	29 (27.4)	14 (34.1)	10 (35.7)		
Epimacular tissue	No	10 (9.4)	6 (14.6)	3 (11.5)	<0.001	
	ERM	93 (87.7)	29 (70.7)	2 (7.7)		
	Ectopic tissue	1 (0.9)	0 (0.0)	18 (69.2)		
	ERM + Ectopic	2 (1.9)	6 (14.6)	3 (11.5)		
Pre-PPV metamorphopsia	No	8 (26.7)	1 (6.2)	1 (9.1)	0.017	
	Yes	22 (73.3)	15 (93.8)	8 (72.7)		
Pre-PPV BCVA (logMAR)	Median (IQR)	0.4 (0.3 to 0.5)	0.4 (0.3 to 0.5)	0.5 (0.4 to 0.7)	0.071	
1-year BCVA (logMAR)	Median (IQR)	0.2 (0.1 to 0.3)	0.2 (0.1 to 0.3)	0.3 (0.1 to 0.4)		
Variable	Category	Combined n (%)	PPV→phaco n (%)	PPV in pseudophakic eyes n (%)	PPV without phaco n (%)	p (modalities)
(B) By surgical modality						
Sex	Male	39 (39.0)	10 (33.3)	22 (56.4)	2 (40.0)	0.201
	Female	61 (61.0)	20 (66.7)	17 (43.6)	3 (60.0)	
Age (years)	<55	2 (2.0)	2 (6.7)	2 (5.1)	2 (40.0)	<0.001
	55–65	13 (12.9)	18 (60.0)	4 (10.3)	1 (20.0)	
	65–75	52 (51.5)	8 (26.7)	16 (41.0)	2 (40.0)	
	>75	34 (33.7)	2 (6.7)	17 (43.6)	0 (0.0)	
Lens status	Clear lens	4 (4.0)	17 (56.7)	—	5 (100.0)	<0.001
	Nuclear sclerosis	31 (30.7)	11 (36.7)	—	—	
	Cataract	64 (63.4)	2 (6.7)	—	—	
	Pseudophakia	—	—	38 (100.0)	—	
Pre-PPV BCVA (logMAR)	Median (IQR)	0.4 (0.3 to 0.5)	0.4 (0.2 to 0.5)	0.4 (0.3 to 0.5)	0.3 (0.2 to 0.7)	0.612
1-year BCVA (logMAR)	Median (IQR)	0.2 (0.1 to 0.3)	0.2 (0.1 to 0.4)	0.2 (0.1 to 0.3)	0.3 (0.3 to 0.3)	0.711

Notes: Data are presented as n (%) unless otherwise indicated. Continuous variables are reported as median (interquartile range, IQR). *p* (subtypes) refers to comparisons across LMH subtypes (tractional, mixed, degenerative). *p* (modalities) refers to comparisons across surgical modalities (combined surgery, PPV→phaco, PPV in pseudophakic eyes, and PPV without phaco). Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate; continuous variables were compared using the Kruskal–Wallis test. Dashes (—) indicate not applicable or not available. Sex data were missing for 1 eye in the degenerative group and for 1 eye in the combined-surgery group. Metamorphopsia data were available for 30 tractional, 16 mixed, and 11 degenerative eyes. Epimacular tissue classification was available for 106 tractional, 41 mixed, and 26 degenerative eyes.

Abbreviations: LMH, lamellar macular hole; PPV, pars plana vitrectomy; PPV→phaco, pars plana vitrectomy followed by phacoemulsification; ERM, epiretinal membrane; IQR, interquartile range; BCVA, best-corrected visual acuity; logMAR, logarithm of the minimum angle of resolution.

Results

A total of 175 eyes from 167 patients (71 men and 96 women) who underwent surgery for lamellar macular hole (LMH) were included. Tractional LMHs were the most frequent subtype (60.6%, $n = 106$), followed by mixed (23.4%, $n = 41$) and degenerative LMHs (16.0%, $n = 28$) ($p < 0.001$). Sex distribution differed significantly among subtypes ($p < 0.001$): tractional LMHs predominated in women (75.5%), whereas mixed (70.7%) and degenerative LMHs (66.7%) were more common in men (Table 1). Regarding surgical modality, 57.7% (101) underwent combined surgery (phacovitrectomy), while 42.3% (74) were treated with sequential surgery, which included vitrectomy followed by phacoemulsification (17.1%), vitrectomy in pseudophakic eyes (22.3%), and vitrectomy without subsequent cataract extraction (2.9%). The choice of surgical sequence (combined vs sequential) was significantly associated with age ($p = 0.008$): combined procedures were more frequent in patients aged ≥ 65 years (68.4% in the 65–75 group and 64.2% in those >75 years), whereas sequential surgery predominated in

younger patients (66.7% in those <55 years and 62.9% in the 55–65 group). This p value corresponds to an analysis in which all sequential modalities were pooled; therefore, it is not shown separately in [Table 1](#).

Preoperative Findings

Preoperative BCVA did not differ significantly among the three LMH subtypes ($p = 0.071$), with a median of 0.4 (0.3–0.5) for tractional and mixed LMHs and 0.5 (0.4–0.7) for degenerative LMHs. No significant differences were observed between the combined and sequential surgery groups (median 0.4 [0.3–0.5]; $p = 0.907$), based on an analysis pooling all sequential modalities. No significant differences were found among the individual sequential subgroups ($p = 0.612$) ([Table 1](#)). Preoperative metamorphopsia was more frequent in mixed LMHs (93.8%) than in degenerative (72.7%) and tractional LMHs (73.3%) ($p = 0.017$) ([Table 1](#)). During follow-up, degenerative LMHs showed a lower likelihood of improvement ($p = 0.002$). In contrast, no significant differences were observed in metamorphopsia evolution when comparing combined versus sequential surgery ($p = 0.505$). These latter analyses reflect follow-up outcomes and are not included in [Table 1](#).

Functional Outcomes

Visual Acuity at 1 Year

1-year BCVA was available for 126 of 175 eyes (72.0%). Follow-up availability decreased progressively beyond the 1-year visit and is summarized in [Supplementary Figure S1](#); descriptive longitudinal BCVA distributions beyond 1 year are shown in [Supplementary Figure S2](#). Among these eyes, best-corrected visual acuity (BCVA, logMAR) at 1 year after vitrectomy did not differ significantly across LMH subtypes and surgical modalities. Median final BCVA was 0.2 logMAR in tractional and mixed LMHs and 0.3 logMAR in degenerative LMHs, with no statistically significant differences between subtypes (pairwise Mann–Whitney U -tests: $p = 0.25$, 0.38, and 0.66) ([Figure 2](#)).

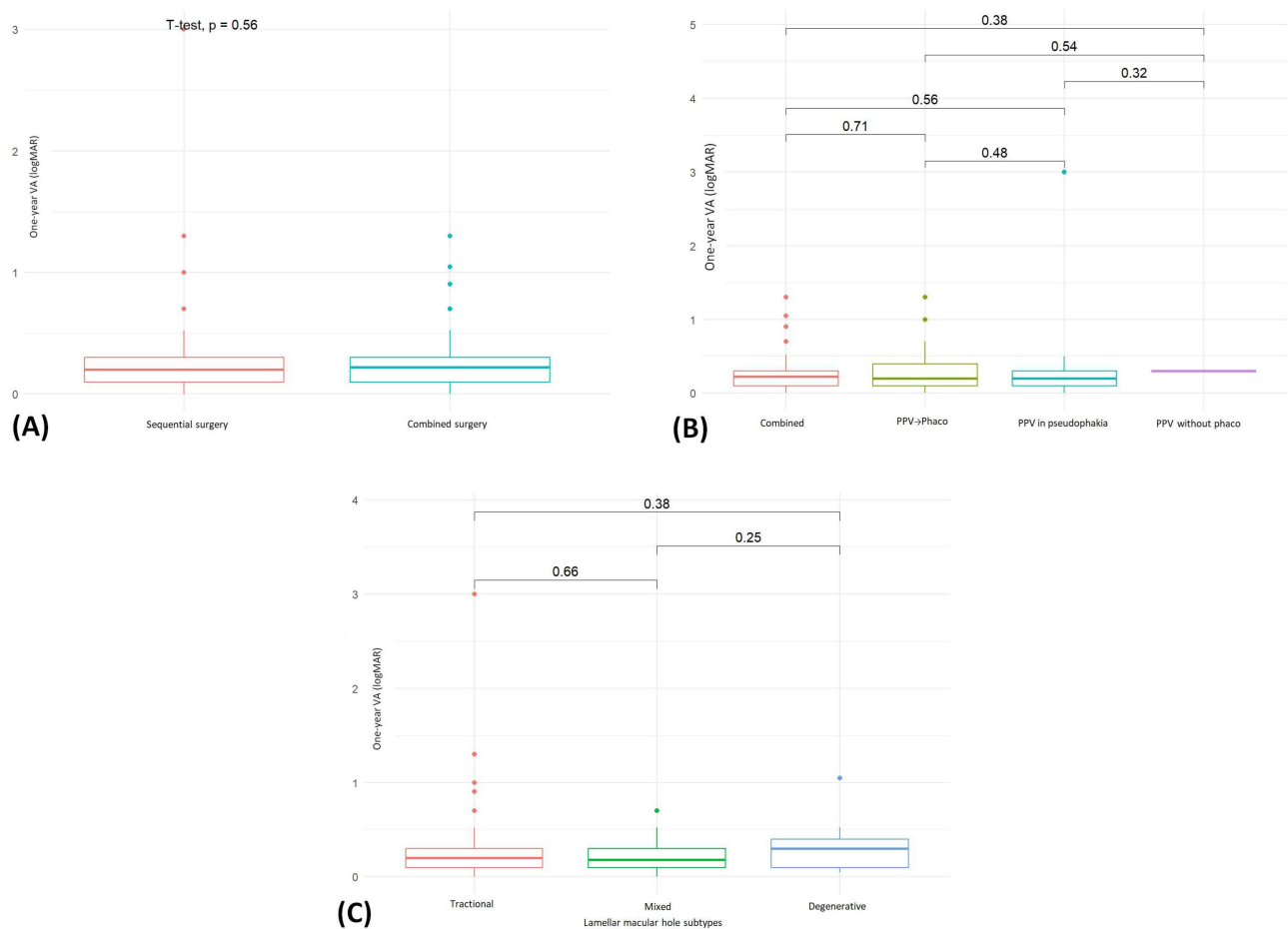


Figure 2 Visual acuity at 1 year after vitrectomy. Boxplots showing best-corrected visual acuity (logMAR) at 1 year according to **(A)** surgical sequence (combined vs. sequential, including all sequential subtypes), **(B)** individual surgical modalities, and **(C)** lamellar macular hole subtype (tractional, mixed, and degenerative).

No statistically significant differences were detected across surgical sequences. The overall comparison between combined and sequential surgery was not statistically significant (0.2 [0.1–0.3] vs 0.2 [0.1–0.3]; Mann–Whitney *U*-test, $p = 0.939$) (Figure 2). When all modalities were analyzed (combined surgery, vitrectomy followed by phacoemulsification, vitrectomy in pseudophakic eyes, and vitrectomy without subsequent cataract extraction), no statistically significant differences were detected (Kruskal–Wallis test, $p > 0.3$) (Figure 2). Final BCVA values were concentrated around 0.2 logMAR in all groups, except in the vitrectomy-without-phacoemulsification group, where it remained at 0.3 logMAR, consistent with the intra-eye analysis.

In the sequential subgroup undergoing vitrectomy followed by phacoemulsification, the median interval between procedures was 11.9 months. In 96% of cases, phacoemulsification was performed before the 1-year visual assessment; therefore, 1-year BCVA generally reflected visual status after completion of the planned surgical sequence, with limited influence from untreated lens opacity.

Given that no statistically significant differences were detected in final BCVA between subtypes and surgical sequences, an intra-eye (intra-individual) analysis was performed to assess the visual change attributable to each surgical component and to quantify the magnitude of postoperative functional improvement (Table 2).

The intra-eye analysis showed significant BCVA improvement across all surgical modalities, except for eyes undergoing vitrectomy without phacoemulsification ($p > 0.99$). In this subgroup, the sample size was small ($N = 5$), and only two eyes completed the 1-year assessment, limiting interpretation. In the sequential group (vitrectomy → phacoemulsification), the BCVA change after vitrectomy alone (prior to cataract surgery) did not reach statistical significance ($p = 0.148$), whereas the overall improvement became significant after subsequent phacoemulsification ($p < 0.001$).

Overall visual gain was -0.2 logMAR, improving from a preoperative median of 0.4 (IQR 0.3–0.5) to 0.2 (0.1–0.3) at 1 year. When evaluating the contribution of each surgical component:

The gain attributable to vitrectomy in pseudophakic eyes was -0.2 logMAR (0.4 [0.3–0.5] to 0.2 [0.1–0.3]; $p = 0.002$). In eyes undergoing sequential surgery with phacoemulsification performed after vitrectomy (PPV→phaco), the gain attributable to cataract extraction was -0.3 logMAR, calculated from pre-phacoemulsification BCVA to 1-month post-phacoemulsification BCVA (0.5 [0.3–0.8] to 0.2 [0.1–0.3]; $p < 0.001$). In eyes that were pseudophakic at the time of vitrectomy, when cataract surgery had been performed before vitrectomy and pre-/post-phacoemulsification BCVA was available, BCVA improved from 0.4 [0.4–0.5] to 0.2 [0.1–0.3] 1 month after phacoemulsification ($p < 0.001$). Combined surgery showed an overall gain of -0.2 logMAR (0.4 [0.3–0.5] to 0.2 [0.1–0.3]; $p < 0.001$). In contrast, vitrectomy without subsequent cataract extraction did not show significant change (0.3 [0.2–0.7] to 0.3 [0.3–0.3]; $p > 0.99$) (Table 2).

Visual Acuity Gain by Subtypes and Surgical Modalities

To assess the net functional effect of surgery, visual acuity gain at 1 year was analyzed according to LMH subtype and surgical modality. Distributions were illustrated using boxplots based on the numerical values shown in (Table 2 and Figure 3). Visual gain (Δ logMAR) was calculated as 1-year logMAR minus preoperative logMAR; therefore, more negative values indicate greater visual improvement. Visual acuity gains did not show marked differences across LMH subtypes and surgical approaches, with median gains of approximately -0.3 logMAR in tractional and mixed LMHs as well as in combined and sequential procedures, and slightly smaller gains in degenerative LMHs. No consistent differences in the overall pattern of improvement

Table 2 Changes in BCVA

Variable	Phacoemulsification Component			Vitrectomy Component			Combined Effect		
	Before ^a	After (1 month) ^a	p-value ^b	Before ^a	After (1 year) ^a	p-value ^b	Before ^a	After (1 year) ^a	p-value ^b
Combined surgery	NA	NA		NA	NA		0.4 (0.3–0.5)	0.2 (0.1–0.3)	< 0.001
Sequential, PPV then phaco	0.5 (0.3–0.8)	0.2 (0.1–0.3)	< 0.001	0.4 (0.2–0.5)	0.2 (0.1–0.4)	0.148	0.5 (0.3–0.8)	0.2 (0.1–0.4)	< 0.001
PPV in pseudophakic eyes	0.4 (0.4–0.5)	0.2 (0.1–0.3)	< 0.001	0.4 (0.3–0.5)	0.2 (0.1–0.3)	0.002	0.4 (0.3–0.5)	0.2 (0.1–0.3)	< 0.001
PPV without phaco	NA	NA		0.3 (0.2–0.7)	0.3 (0.3–0.3)	> 0.99	0.3 (0.2–0.7)	0.3 (0.3–0.3)	> 0.99

Notes: (a) Median (IQR). (b) Wilcoxon signed-rank test with continuity correction (paired).

Abbreviations: NA, not applicable; PPV, pars plana vitrectomy; phaco, phacoemulsification. For the phacoemulsification component, “Before” indicates BCVA immediately before phaco and “After” indicates BCVA 1 month after phaco. For the vitrectomy component, “Before” indicates pre-PPV BCVA and “After” indicates BCVA at 1 year after PPV.

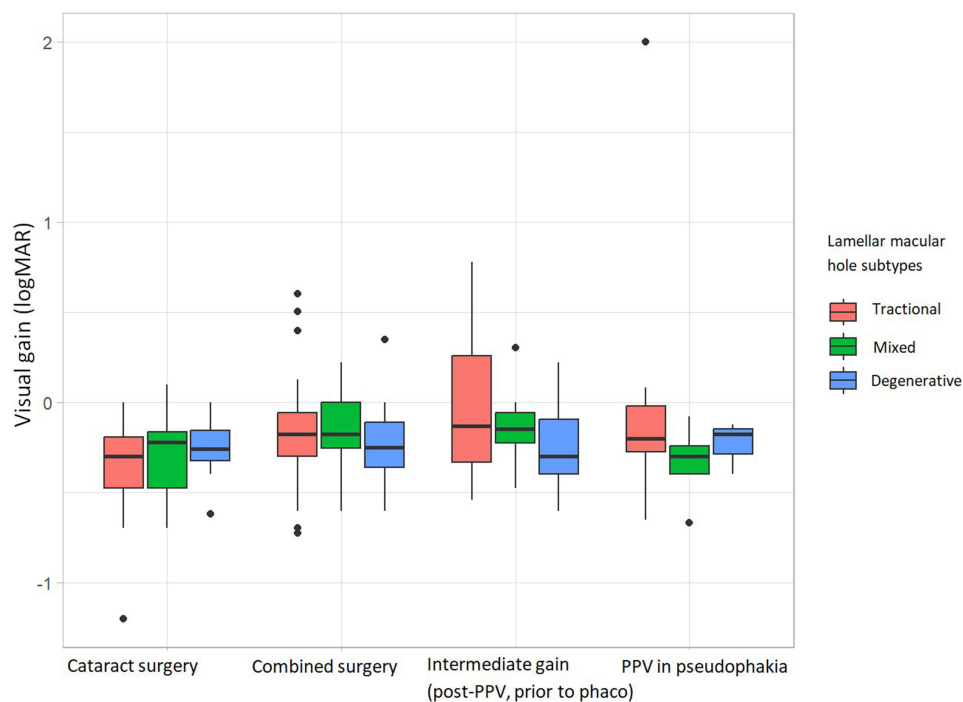


Figure 3 Visual acuity gain by surgical component and lamellar macular hole subtype. Boxplots showing visual acuity gain (Δ logMAR) according to surgical component and stratified by lamellar macular hole subtype (tractional, mixed, and degenerative). Visual gain was calculated as postoperative logMAR minus preoperative logMAR; therefore, more negative values indicate greater visual improvement. The categories shown correspond to cataract surgery, combined surgery, intermediate gain after vitrectomy before subsequent phacoemulsification, and vitrectomy in pseudophakic eyes.

were observed. Given that final visual acuity converged to a narrow range of values across groups, a ceiling-effect analysis was conducted to identify factors associated with achieving high postoperative visual outcomes and to better understand potential functional limits to recovery. Preoperative visual acuity ($p = 0.013$) and epimacular tissue type ($p = 0.032$) emerged as the main associated factors. Patients with isolated epiretinal membrane (ERM) showed a higher likelihood of reaching a final BCVA ≤ 0.22 logMAR at 1 year (57.8%) compared with those without epiretinal tissue (26.7%) and those with ectopic inner foveal tissue alone (38.5%) or combined with ERM (16.7%). Age was also significantly associated with achieving this threshold ($p = 0.010$), with the highest rates observed in patients aged 55–75 years (57–65%) and lower rates in patients <55 years (33.3%) and >75 years (27.3%).

To jointly assess the effect of these and other variables on final visual acuity while accounting for the inclusion of both eyes from some participants, a linear mixed-effects model with a random intercept for patient was fitted. The model included baseline BCVA, age, lens status at surgical planning, LMH subtype, and surgical modality as fixed effects. In this analysis, baseline BCVA was the only independent predictor of 1-year BCVA ($\beta = 0.60$; 95% CI 0.32–0.89; $p < 0.001$), whereas age, lens status, LMH subtype, and surgical modality were not significantly associated with the outcome. Full model estimates are shown in [Supplementary Table S3](#).

Sensitivity and exploratory analyses supported the robustness and interpretation of the main findings. Excluding the very small “PPV without phacoemulsification” subgroup did not change the overall interpretation, with no clinically meaningful differences in 1-year BCVA between surgical strategies. To explore potential attrition bias, eyes with available 1-year BCVA were compared with those lacking this outcome. Eyes without 1-year follow-up were older (mean 73.2 vs 68.3 years; $p = 0.004$), showed slightly worse baseline BCVA (0.5 vs 0.4 logMAR; $p = 0.016$), and differed in lens status ($p = 0.010$) and surgical sequence distribution ($p = 0.001$). However, no significant differences were found in LMH subtype ($p = 0.982$), epimacular tissue type ($p = 0.525$), or intermediate postoperative BCVA recorded between 3 and 12 months after PPV ($p = 0.472$). In addition, an exploratory comparison across centers showed no statistically significant differences in baseline LMH subtype distribution ($p = 0.191$) or baseline BCVA ($p = 0.750$), whereas the distribution of surgical sequence differed significantly between sites ($p < 0.001$). Detailed results of these analyses are provided in [Supplementary Tables S4](#) and [S5](#).

Discussion

In this multicenter observational study, we describe the distribution of OCT-defined LMH subtypes and baseline characteristics and relate these findings to functional outcomes after surgery. The tractional subtype was the most frequent, followed by mixed and degenerative LMHs, consistent with most published case series.⁹ However, population-based studies have not specifically reported the prevalence of LMH subtypes.^{5–8}

Regarding sex distribution, tractional LMHs were more common in women, whereas mixed and degenerative subtypes predominated in men, a trend also described previously,¹⁹ although it did not remain significant after adjustment for age.

We observed a predominance of combined surgery over sequential procedures, which likely reflects the cohort's age distribution. Most patients were in the 65–75 and >75-year age groups, in whom cataract is common and often supports selection of a combined approach. Conversely, in younger patients, a sequential strategy was more frequently chosen, with vitrectomy performed first and phacoemulsification deferred to a later stage. This pattern was consistent with lens status at the time of surgical planning: cataract predominated in the combined group, whereas pseudophakia or a clear crystalline lens was more common in the sequential group, reinforcing the relationship between age, lens status, and surgical decision-making.

Preoperative BCVA did not differ significantly across LMH subtypes or surgical modalities, although degenerative LMHs tended to present slightly worse baseline values. Metamorphopsia assessment remains subjective, and evidence regarding predictors of postoperative evolution is limited.²⁰ In our cohort, surgical sequence did not influence metamorphopsia outcomes; however, the degenerative subtype was associated with less favorable functional outcomes, with greater persistence of visual distortion after surgery. In contrast, mixed and tractional LMHs showed more variable courses, although the mixed subtype exhibited the highest prevalence of preoperative metamorphopsia, consistent with prior reports describing a strong association between this phenotype and metamorphopsia.²¹

Although metamorphopsia is clinically relevant in LMH, it was not used as a primary outcome because its retrospective documentation was not protocolized and showed substantial heterogeneity across clinical records and centers. In addition, its quantification in routine practice was not sufficiently standardized to support robust comparative analysis as a primary endpoint.

From a methodological standpoint, visual acuity was assessed at 1 year after vitrectomy because this was considered a clinically meaningful time point to reflect a more stable postoperative functional outcome than earlier visits. In the sequential surgery group, nearly all patients had undergone cataract extraction before the 1-year assessment, thereby reducing the potential confounding effect of lens opacity. For these reasons, 1-year BCVA was considered the most appropriate primary functional endpoint for comparing surgical strategies. Longer follow-up was not selected as the main endpoint because it was less consistently available in routine clinical records and could increasingly reflect the influence of age-related ocular comorbidities rather than the direct functional effect of LMH surgery. Follow-up availability over time is summarized in [Supplementary Figure S1](#), and descriptive BCVA distributions beyond 1 year are provided in [Supplementary Figure S2](#). These additional data support the choice of 1-year BCVA as the most methodologically robust and clinically interpretable primary endpoint in this cohort. Within this framework, the study did not detect statistically significant differences in 1-year visual acuity across LMH subtypes or surgical modalities, suggesting that the choice between combined and sequential surgery may reasonably be individualized according to patient characteristics, as no statistically significant differences in visual outcomes were detected in this cohort. Although not statistically significant, degenerative LMHs tended to achieve slightly worse final visual acuities, consistent with greater structural disruption and a reduced potential for functional recovery.

The intra-eye (intraindividual) analysis showed significant visual improvement across most surgical modalities. However, two scenarios merit specific consideration. In the sequential cohort, improvement after vitrectomy alone—prior to cataract extraction—did not reach statistical significance, with greater variability, particularly among tractional LMHs. This pattern may relate to heterogeneity during the interval between procedures and to the influence of cataract progression on visual function during that period.

Eyes undergoing vitrectomy without phacoemulsification also did not show meaningful visual change. Given the small sample size and loss to follow-up, these findings should be interpreted cautiously due to potential selection bias. Notably, patients in this group presented with relatively good baseline visual acuity and maintained stable values at

1 year, suggesting that in such cases the surgical aim may be preservation of visual function rather than additional gain. Conversely, eyes with worse baseline visual acuity had greater room for improvement, although their recovery tended to plateau at more modest visual levels and did not reach the higher outcomes observed in patients with better preoperative vision.

The limited dispersion of 1-year mean visual acuity values across groups, together with the stability observed in the intra-eye comparisons, suggested a potential ceiling effect in postoperative functional recovery. In the ceiling-effect analysis, preoperative visual acuity emerged as the main factor associated with achieving a final BCVA ≤ 0.22 logMAR, with patients presenting better baseline vision showing a higher likelihood of reaching high postoperative functional levels. Although absolute gain was more limited in these eyes, they had a greater probability of attaining excellent visual outcomes.

Macular morphology also appeared to influence prognosis: eyes with isolated epiretinal membrane (ERM) showed the highest rates of favorable visual recovery, whereas the absence of epiretinal tissue or the presence of ectopic inner foveal tissue—features typically associated with more degenerative phenotypes—were linked to worse outcomes. Age demonstrated a non-linear, U-shaped association, with the most favorable results observed in patients aged 55–75 years and a reduced probability of achieving high visual acuity at the extremes of age. This pattern may reflect a higher proportion of more complex presentations among younger patients, whereas in patients older than 75 years cumulative structural degeneration, ocular comorbidity, and reduced macular functional reserve may limit postoperative recovery. Taken together, baseline functional status, macular architecture, and age seem to jointly determine the maximal “visual ceiling” achievable after surgery.

Consistently, the mixed-effects multivariable analysis, which accounted for patient-level clustering when both eyes were included, reinforced these observations by showing that baseline BCVA was the only independent predictor of 1-year visual acuity. Neither surgical modality, LMH subtype, age, nor lens status showed a significant independent association with the final outcome after adjustment. This finding, aligned with the ceiling-effect analysis, underscores baseline vision as a key determinant of postoperative prognosis: patients with better initial visual acuity tend to maintain high functional levels but with limited absolute gain, whereas those with poorer baseline vision may experience larger relative improvements yet rarely achieve values close to 0 logMAR, likely due to pre-existing foveal damage. In this context, LMH surgery may primarily stabilize anatomical and functional decline rather than fully reverse established damage. Therefore, timing of surgery may be critical to optimize prognosis: intervening at earlier stages—when visual acuity remains relatively good (≈ 0.2 – 0.25 logMAR) but symptoms or morphological progression are present—may help preserve high functional levels, albeit with limited gain, provided that the risk–benefit balance of surgery is carefully considered.

Sensitivity and exploratory analyses also help contextualize the observational nature of the cohort. Excluding the very small “PPV without phacoemulsification” subgroup did not materially change the overall interpretation. In addition, eyes without 1-year BCVA differed from followed eyes in age, lens status, surgical sequence, and baseline BCVA, indicating that follow-up availability was not completely random. One plausible explanation is that, in routine practice, eyes undergoing PPV followed by phacoemulsification may be monitored more closely because vitrectomy itself often accelerates cataract progression and therefore creates a clinical need for subsequent cataract assessment and surgery. By contrast, eyes already pseudophakic at the time of PPV do not require this additional lens-related follow-up, which may partly explain their lower representation among eyes with complete 1-year data. The slightly worse baseline BCVA observed among eyes without 1-year follow-up may also have been influenced, at least in part, by the greater proportion of cataract present at initial surgical planning, although this interpretation remains exploratory. Reassuringly, no significant differences were detected between followed and non-followed eyes in LMH subtype, epimacular tissue, or intermediate postoperative BCVA recorded between 3 and 12 months after PPV. Likewise, the absence of major between-center differences in baseline LMH subtype distribution and baseline BCVA, together with significant variation in surgical sequence, suggests that treatment allocation reflected local routine practice patterns more than major differences in baseline case mix.

This Study Has Limitations

Its observational design and retrospective data analysis led to incomplete availability of some variables and missing 1-year BCVA in a proportion of eyes, which may introduce selection bias. In addition, unmeasured confounding related to cataract severity, referral patterns, surgeon preference, and nonrandomized surgical allocation cannot be fully excluded. Although within-patient clustering was addressed in the mixed-effects multivariable analysis, the observational design and incomplete

follow-up still limit causal interpretation. In addition, the available sample was powered to detect only moderate between-group differences, and smaller differences may have remained undetected. Preoperative lens status was clinically categorized from the medical record, but cataract severity was not graded using a standardized quantitative classification system across centers. Other patient-relevant functional outcomes, particularly metamorphopsia, were not uniformly documented or quantified across centers and therefore could not be analyzed with the same methodological consistency as BCVA. Longer-term follow-up was less consistently available in routine clinical records and may also have been increasingly influenced by age-related ocular comorbidities. In addition, the comparisons of followed versus non-followed eyes and across participating centers were exploratory and should be interpreted cautiously, particularly because some center-level subgroups were small. These limitations are unlikely to fully explain the overall findings, but they should be considered when interpreting and generalizing the results. Because the inclusion period spans more than a decade, ancillary aspects of PPV technique—particularly approaches to epimacular tissue delamination—may have evolved over time. However, all cases were performed using 23-gauge instrumentation across centers. Accordingly, these results are most likely generalizable to similar tertiary-care settings managing OCT-confirmed LMH with 23-gauge PPV, although external validity may vary across healthcare systems and surgical practices.

Conclusion

In this cohort, lamellar macular holes were most commonly diagnosed in patients aged 65–75 years and frequently coexisted with cataract. Vitrectomy was associated with significant visual improvement at 1 year, and no statistically significant differences were detected between combined and sequential approaches. These findings support individualized selection of surgical sequence according to patient characteristics, lens status, and shared patient–surgeon preferences.

Data Sharing Statement

Individual participant-level data are not publicly available due to patient confidentiality and institutional/ethical restrictions. De-identified aggregated data supporting the findings of this study may be made available from the corresponding author upon reasonable request, subject to approval by the participating institutions and any applicable data-sharing agreements.

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