Factors affecting anatomical and visual outcome after macular hole surgery: findings from a large prospective UK cohort

Running title: Macular hole surgery outcomes.

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Conflict of Interest

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Abstract

Objectives

To reassess the definition of a large macular hole, factors predicting hole closure and post-surgery visual recovery.

Design

Database study of 1,483 primary macular hole operations. Eligible operations were primary MH operations treated with a vitrectomy and a gas or air tamponade. Excluded were eyes with a history of retinal detachment, high myopia, vitrectomy or trauma.

Results

A higher proportion of operations were performed in eyes from females (71.1%) who were 'on average' younger ($p < 0.001$), with slightly larger holes ($p < 0.001$) than male patients. Sulpha hexafluoride gas was generally used for smaller holes ($p < 0.001$).

From 1,253 operations with a known surgical outcome, successful hole closure was achieved in 1,199 (96%) and influenced by smaller holes and complete ILM peeling ($p < 0.001$), but not post-surgery positioning ($p = 0.072$). A minimum linear diameter of approximately 500 microns marked the threshold where the success rate started to decline.

From the 1,056 successfully closed operations eligible for visual outcome analysis, visual success (defined as visual acuity of 0.30 or better logMAR) was achieved in **488 (46.2%) eyes**. At the multivariate level, the factors p**redicting visual success were better pre-operative VA, smaller hole size, shorter duration of symptoms and absence of AMD.**

Conclusions

Females undergoing primary macular hole surgery tend to be younger, and have larger holes than male patients. The definition of a large hole should be changed to around 500 microns, and patients should be operated on early to help achieve a good post-operative VA.

Introduction

Idiopathic age related macular holes (MH) are a common cause of significant visual impairment, with a prevalence of up to 1 in 200 in the over 60-year-old age group and are bilateral in up to 10% of patients.[1] Following the first report of successful treatment with vitrectomy and short acting gas tamponade in 1991, they are now routinely treated surgically, where the aim is to close the hole, which typically results in an improvement in vision.[2] Hole closure rates are high at over 90% but various factors are known to reduce the success rate, in particular the size of the hole. A number of surgical variations and adjunctive procedures have been described to improve hole closure rates including postoperative face down positioning, longer acting tamponade, surgical creation of ILM flaps, and other biological membranes, and platelets.[3,4] The benefit of these variations is unclear and the optimum MH size threshold to deploy them is also uncertain. Furthermore, although surgical hole closure is the chief determinant of visual acuity postoperatively, the extent of visual improvement in surgically closed cases is variable with approximately 55% improving by at least 0.30 logMAR units, but only 35% achieving an acuity of 0.30 logMAR or better in a recent large UK audit.[5] Although several variables affecting postoperative vision have been described, their effect size has not been clearly defined. This is particularly important for those factors which could be potentially modifiable including hole duration, tamponade choice and postoperative posturing.

To identify and quantify the factors that affect MH closure, and the visual outcome in those that close, we examined the visual and anatomical outcomes in a cohort of 1,483 MHs treated by vitrectomy and gas tamponade who had prospective data collection as part of a national speciality group study. Furthermore, we sought to redefine the threshold for a large macular hole, at which typical closure rates start to decline.

Methods

The data was extracted from the BEAVRS Vitreoretinal database with a data collection period from November 2015 to August 2018. [6] The database is compliant with the Royal College of Ophthalmologists' National MH dataset. [7]

The BEAVRS database is an online web application for the collection, and analysis, of anonymised vitreoretinal surgical data including MH. Under UK guidance the data collection is regarded as audit for the purposes of service evaluation and as such ethical approval is not required, but Caldicott approval was obtained from each participating Hospital Trust to allow data compilation. Data is entered prospectively immediately following surgery and again when follow up is complete, at least 4 weeks post-surgery or after all gas had dissolved. A variety of preoperative, perioperative and postoperative details are included. Minimum linear diameter is defined in the on line collection tool with the measurement technique illustrated, and as per previously described.[8] Successful closure, defined as closure without a neurosensory retinal defect, or not of the macular hole was recorded by the operating surgeon after post-operative assessment.

Eligible operations were primary MH operations treated with a vitrectomy and a gas or air tamponade. Excluded from the analysis were MH associated with retinal detachment, high myopia (> 6 dioptres of myopia) or trauma, previously vitrectomised eyes, and those in whom silicone oil was used. Acuity data recorded in Snellen were converted to a logMAR equivalent. LogMAR visual acuity values representing 'count fingers' and 'hand movements' were replaced with 1.98 and 2.28 respectively in numeric calculations.[9,10] Operations with less than four weeks follow up were not included in any postoperative VA analysis. Operations with a preoperative VA equivalent to ≤0.30 logMAR or those that included air or oil tamponade were not included in the visual outcome modelling.

The probability of a postoperative visual acuity equivalent to ≤0.30 logMAR (6/12 or better) and anatomical closure were modelled separately using multivariable logistic regression. All covariates under consideration were investigated at the univariate level using χ^2 tests. Any covariate with a p-value <0.10 progressed to multivariable modelling where the full model was fitted and backward selection employed. A p-value of <0.05 plus assessment of Akaike Information Criterion and the area under the receiver operating curve were used for final covariate selection.

Robust standard errors where calculated using bootstrapping with 100 replications and clustering of the individual consultant responsible for the patient care, where the operations performed by the consultant surgeon were considered as a separate cluster to the operations performed by a trainee surgeon under their supervision.

The covariates considered were the patient's age and gender, the preoperative VA, the duration of symptoms, size of hole, vitreous attachment status, type of tamponade used during surgery, lens status, completion of internal limiting membrane peel, presence of age-related macular degeneration (AMD), surgeon grade and the post-surgery posture positioning.

Continuous data was compared using the Student's t-test with Welch adjustment for unequal variances or ANOVA. Comparisons of follow up time were compared using non-parametric tests and categorical data by Chi-squared tests or univariate logistic regression. All analyses were conducted using STATA version 14, (StataCorp. 2009. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP).

Results

From 1,527 macular hole operations, 44 (2.9%) were excluded from the analysis; 24 operations were associated with previous retinal detachment, 9 in highly myopic eyes, 8 operations in vitrectomised eyes, 1 non-primary MH operation, 1 trauma operation and 1 operation that included silicone oil. There were therefore 1,483 primary MH operations eligible for analysis where 735 (49.6%) operations were performed in left eyes and 748 (50.4%) in right eyes.

Thirty-five consultant surgeons performed 1,245 (84.0%) operations and 238 operations were performed by trainee surgeons. The median number of operations performed by consultant surgeons was 30 (range; 1 – 132).

Age-related macular degeneration was present in 58 (3.9%) eyes, amblyopia in 12 (0.8%) eyes, glaucoma in 23 (1.6%) eyes and unspecified 'other' in 44 (3.0%) eyes. The macular hole was associated with an epiretinal membrane in 220 (14.8%) eyes and 229 (15.4%) eyes had previously undergone cataract surgery.

The vitreous had detached from the fovea prior to surgery in 565 (38.1%) eyes, with complete posterior vitreous detachment present in 151 (10.2%) eyes (i.e. stage 4 holes), attached with traction in 374 (25.2%) eyes and not recorded for 393 (26.5%) eyes.

Demographics;

A higher proportion of operations were performed in eyes from females (71.1%) who were 'on average' younger than the males undergoing surgery, (means in years; 68.9 for females vs. 71.7 for males, $p < 0.001$).

Female patients generally had slightly larger holes than male patients (means in microns; 414.8 for females vs. 366.3 for males, $p < 0.001$), Figure 1a.

The duration of symptoms prior to the time of surgery was known for 732 (49.4%) operations and uncertain for 751 (50.6%) operations. When known the median duration was 3 months, with 6.8% having symptoms for greater than 12 months. There was no difference in the duration between the genders (mean duration months; 4.9 for females vs. 4.6 for males, $p = 0.4222$), Table 1.

Treatment;

Vitrectomy was performed in all operations, 756 (51.0%) using a 23 gauge, 515 (34.7%) a 25 gauge, 65 (4.4%) a 27 gauge and for 147 (9.9%) operations the vitrectomy gauge was not recorded.

Internal limiting membrane peeling was completed for 1,393 (93.9%) operations, incomplete for 30 (2.0%) operations and not recorded for 60 (4.1%) operations. Combined phacoemulsification was carried out in 851 (57.4%) operations, meaning 403 eyes were phakic at the completion of surgery.

The ocular tamponade used was sulpha hexafluoride gas in 304 (20.5%) operations, perfluoroethane gas in 1,009 (68.0%) operations, perfluoropropane gas in 166 (11.2%) operations and air in 4 (0.3%) operations.

Hole size;

Overall the size of the macular hole was approximately normally distributed around a mean of 400 microns and a standard deviation of 156 microns, although there is a suspicion of measurement rounding around 300 microns, Supplementary Figure 1. The macular hole size was <250 microns for 241 (16.3%) eyes, 250 – 400 microns for 508 (34.3%) eyes and >400 microns for 734 (49.5%) eyes.

The use of ocular tamponade was strongly associated with the size of the hole, where sulphur hexafluoride gas was generally used for smaller holes (mean 333.5 microns) than perfluoroethane gas (mean 401.5 microns) or perfluoropropane gas (mean 526.5 microns), this distribution difference was statistically significant ($p < 0.001$), Supplementary table 1 and Figure 1b.

Operative complications;

A retinal break was recorded for 235 (15.8%) operations, with no statistical difference between the vitrectomy gauge used, the ocular tamponade used or if the hole was successfully closed post-operatively. Lens touch was recorded for 10 (0.7%) operations and unspecified 'other' operative complication for 31 (2.1%) operations.

Hole closure and hole size;

Of the 1,483 macular hole operations the anatomical outcome was known for 1,253 (84.5%) operations, in which macular hole closure was achieved in 1,199 (95.7%) operations.

The mean MLD for the 230 cases where the outcome was unrecorded was 406 microns with 24.8% greater than 500 microns, compared to 400 microns and 24.3% greater than 500 microns for the remaining 1,253 eyes.

The probability of successful macular hole closure was linked to the size of the hole, where for holes of <400 microns the failure rate was 1.1% (7/637), holes between 400 and 599 microns 3.1% (9/292), holes between 500 and 599 microns 10.5% (20/191) and for holes of ≥600 microns 13.5% (18/133), Figure 2.

The receiver operating curve for failure and hole size had an area under the curve of 77.9% (95% CI; 75.5% to 80.2%) and the hole sizes that equated to the points where the sensitivity and specificity were both >70% were 464 – 500 microns, Supplementary Figure 2.

Failed hole closure occurred in 17.9% (5/28) eyes with incomplete ILM peeling, 4.1% (48/1,179) eyes with complete ILM peeling and in 2.2% (1/46) eyes with unknown ILM peeling status (p <0.001). Macular hole closure was not influenced by the vitreous attachment status (p = 0.215), the type of tamponade used (p = 0.125), vitrectomy gauge size (p = 0.476) or post-surgery posturing position, with failure rates of 3.8% (37/982) and 6.3% (17/271) for prone vs. not-prone positioning respectively (p = 0.072). For eyes with holes <500 microns the hole closure failure rates were 1.5% (11/726) and 2.5% (5/203) for prone vs not-prone positioning respectively (p = 0.359), and for eyes with holes ≥500 microns the hole closure failure rates were 10.2% (26/256) and 17.6% (12/68) for prone vs. not-prone positioning respectively (p = 0.088), Supplementary table 2.

Visual acuity;

The mean preoperative acuity for all eyes was 0.92 logMAR, and the median was 0.78.

From the 1,199 operations that were successfully closed, 121 (10.1%) operations are excluded from postoperative VA analysis due to less than four weeks follow up. From 1,078 operations the median postoperative VA was 0.42 logMAR (Snellen 6/16) (range; -0.30 – HM). The postoperative VA was ≤0.30 logMAR (Snellen 6/12 or better) for 506 (46.9%) eyes and between 0.31 and 1.00 logMAR (Snellen >6/12 – 6/60) for 531 (49.3%) eyes.

From 621 eyes with a preoperative VA equivalent to between 0.31 and 1.00 logMAR, 57.8% had a postoperative VA equivalent to ≤0.30 logMAR. The median follow-up was very similar for the different levels of postoperative VA, Supplementary table 3.

Any post-surgery improvement in vision was achieved for 1,012 (93.9%) eyes and a gain in vision of ≥0.30 logMAR by 692 (64.2%) eyes.

Visual success;

From the 1,199 operations that were successfully closed, 121 (10.1%) operations are excluded from postoperative VA analysis due to less than four weeks follow up. From 1,078 operations 19 (1.8%) eyes were excluded from the visual success analysis as their preoperative VA was ≤0.30 logMAR (Snellen 6/12). A further 3 eyes were excluded as the ocular tamponade used during surgery was air. Eligible for visual **success analysis were 1,056** primary macular hole operations, **488 (46.2%)** of these eyes **achieved a postoperative vision of 0.3 logMAR or better, and 568 (53.8%)** eyes **did not.**

Visual success was more often achieved for male patients than female patients (53.0% vs. 43.5%, p = 0.005), in eyes with a better preoperative VA (p < 0.001), for smaller holes (p < 0.001), for shorter duration of symptoms when the duration was known (p <0.001), in eyes without AMD (**47.3% vs. 19.5%, p = <0.001), for operations that used sulpha hexafluoride gas or perfluoroethane gas instead of perflouropropane gas (53.6% vs. 46.6% vs. 33.1%, p = 0.001) and for operations with completed internal limiting membrane peeling instead of incomplete peeling or not recorded peeling status (46.9% vs. 23.8% vs. 41.0%, p = 0.089).** No statistically significant differences in the visual success rates were observed for the grade of operating surgeon, lens status, vitreous attachment status **or post-surgery posturing position, Table 2.**

At the multivariate level, the factors influencing visual success were the preoperative VA, hole size, duration of symptoms and presence of AMD, Table 3. The model area under the receiver operator curve was 71.72%, Supplementary Figure **3.**

Discussion

Using prospective data from a cohort of over 1,400 eyes this study has clarified and quantified factors that predict macular hole closure and visual outcome. Our anatomical and visual results are consistent with previous large studies confirming high hole closure rates and visual success rates. [5,11-14] **Essex et al recently presented their findings from Australia on over 2,000 macular holes.**[12] **Their study differs from ours in terms of hole size with generally smaller holes with a median hole size of 280 microns and 23% of holes being greater than 400 microns compared to a median of 394 microns and 57% greater than 400 microns in this study. To go along with this their preoperative visual acuity was also better at a mean of 48.7 letters (approximately 0.73 logMAR). Our study is unique in**

terms of previous database studies in having purely prospective data collection in a public sector healthcare setting and having size data on all holes.

The strongest predictor of hole closure was hole size. We found that hole closure remains fairly constant at around 97-98% until a size of around 500 microns in minimum linear diameter, and then reduces to around 90% for holes between 500 and 599 microns and 87% for holes greater than 600 microns (see Figure 2). The presence of VMT was unrelated to hole closure rates or indeed hole size as others have found. [15] The completeness of ILM peeling was a significant factor predicting closure as has been clearly established.[16] Some degree of postoperative prone posturing was recommended in approximately 80% of patients but was unrelated to hole closure, although it is possible that this sample is too small to detect any true effect of post-surgery positioning. If an effect of positioning in large holes size truly does exist it must be small. The rationale for using a size of 400 microns to define large for macular holes is unclear and appears to have been based on Gass's original work pre-dating surgery and relating to slit lamp biomicroscopy findings rather than OCT. [17] The 400-micron size point was continued in the classification suggested by the International vitreomacular traction study group in 2013. [18] There is no doubt that macular holes over 400-microns have a lower surgical success rate than those under 400, but the break point where this reduction occurs is unclear. [19] Our data suggests it is non-linear and Ch'ang et al have recently suggested a size cut off of 630 microns based on a study of 258 eyes over 400-microns in size undergoing surgery with C2F6 or C3F8 gas. [20] Examination of their ROC curve for anatomical closure using macular hole size as a predictor shows a fairly low profile covering a number of possible values and our larger series would suggest a lower cut off point of 500-microns. Gupta et al and Salter et al. similarly found a cut off of around 500-microns albeit in far smaller studies. [21,22] We would suggest that this cut-off point of 500 microns could be used as a new pragmatic size definition of large for the surgical treatment of macular holes, where the surgical success rate starts to reduce. Several interventions have been suggested to improve closure rates in larger holes including ILM flaps, retinal massage, retinal expansion, amniotic membrane, blood or platelets and retinal free flaps. [4,23-28] The exact size point at which these various options are chosen would depend however on any extra morbidity introduced by the technique.

The cohort consisted of a consecutive series of eyes with data entered prospectively by a group of 35 surgeons from across the UK, using an approved and validated online data collection methodology. As expected females formed approximately 70% of the cohort and interestingly, they had a significantly greater hole size than the males. This has not been found before as far as we are aware, although Forsaa et al found a similar but non-significant trend in a series of 152 primary MH.[29] Macular hole size has been shown to be related to foveal floor size which is associated with foveal avascular zone (FAZ) size.[30, 31-33] Interestingly female gender is associated with larger FAZ size as well as a thinner foveal floor thickness which might explain our findings. [34, 35]

Most of the surgery was carried out using 23 or 25gauge transconjunctival vitrectomy with retinal break formation rate in line with previous studies and with no difference between the gauges. It should be noted that all surgeries were carried out using cannulated sclerostomy systems which have been shown to reduce entry site breaks. [36,37] Perfluoroethane (C2F6) was used in almost 70% of the cases, with a strong tendency for SF6 to be used in smaller holes and C3F8 to be used in those with the largest holes. Despite this surgeon rationale we found no evidence that gas type was related to hole closure nor visual success on multivariate analysis.

The factors that were most closely associated with visual success were preoperative VA and hole size, as others have reported, however we also found two other factors which have been less clear in the literature to date. [12, 21] The duration of the macular hole prior to surgery was an important predictor, halving the chances of visual success in those with durations longer than 4 months, and similar to the effect size of hole dimensions and preoperative VA. Others studies have reported similar findings, although it has not been extensively investigated and importantly, unlike hole size and preoperative VA, it is potentially modifiable.[12,14,38-40] The duration we measured was cumulative hole duration at the time of surgery. The patient may have gone through several steps to reach this stage, including diagnosis by their primary care physician or optician, referral to a general ophthalmologist and then onward referral to retinal specialist before finally undergoing surgery. Minimising time to surgery will improve outcome. Finally, the presence of AMD significantly affected the postoperative vision as might be expected, but not age alone, as other have found. [12,14] This is important as older patients with macular holes can achieve good visual results if AMD is not present. Closure was also unaffected by age.

Cataract is the most common complication of macular hole surgery, and many surgeons advocate combined clear lens extraction and vitrectomy. [41,42] The rate of combined phacovitrectomy in this series was high at 57% compared to only 13% in the study by Essex et al. [12] We did not find any evidence of any difference in anatomical or visual outcomes in the eyes that had combined surgery compared to eyes that were left phakic. This may be because the follow-up was relatively short, and phakic patients had not developed visually significant cataract. Although combined surgery is more convenient for patients, and reduces costs for the health care provider, we found no evidence that it affects outcomes.

Limitations for this study include no patient identifier to use patients as a cluster variable in the modelling; however, we believe that <10% of the sample would have had bilateral MH surgery. The BEAVRS audit database does not include a surgeon identifier for the trainee surgeon, although not many centres will have more than one trainee surgeon, and vitreoretinal surgery trainees are supervised by the consultant who is responsible for the patient care. The duration of symptoms was not known for approximately 50% of operations, although this is a reflection of clinical practice as the patient will not always be able to state how long they have had symptoms. There is a suspicion of measurement rounding of the hole size at around 300 microns, although this value corresponds to the lowest risk of failed hole closure failure and poor post-surgery vision. The multivariate modelling should be viewed as provisional given the relatively small sample, possible measurement rounding and high rate of missing duration of symptom data. 15% of eyes did not have anatomical outcome data recorded and were excluded, but with MLD being the main predictor for anatomical success and their similarity in size to the 85% with outcome data included, we think it is unlikely that this would confound our results. We did not include details of the extent of ILM peeling nor the experience of the Consultant surgeons who took part both of which may have had effects on outcome. Finally, the sample is relatively small for the number of comparisons that have been conducted which does increase the chance of type I errors.

In conclusion in a large prospective database study we have defined the factors that predict hole closure and visual outcome in macular hole surgery. We have found that hole closure remains fairly constant at around 97-98% until a size of around 500 microns in minimum linear diameter, and then reduces with increasing hole size, suggesting this could be used as a new definition of large in future studies and clinical practice. In terms of visual success in those holes that closed, we found that better preoperative VA, smaller hole size, shorter duration of symptoms and absence of AMD were significant predictors in multivariate analysis.

Supplementary information is available at Eye's website (https://www.nature.com/eye)

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Titles and legends to figures

Figure 1a:

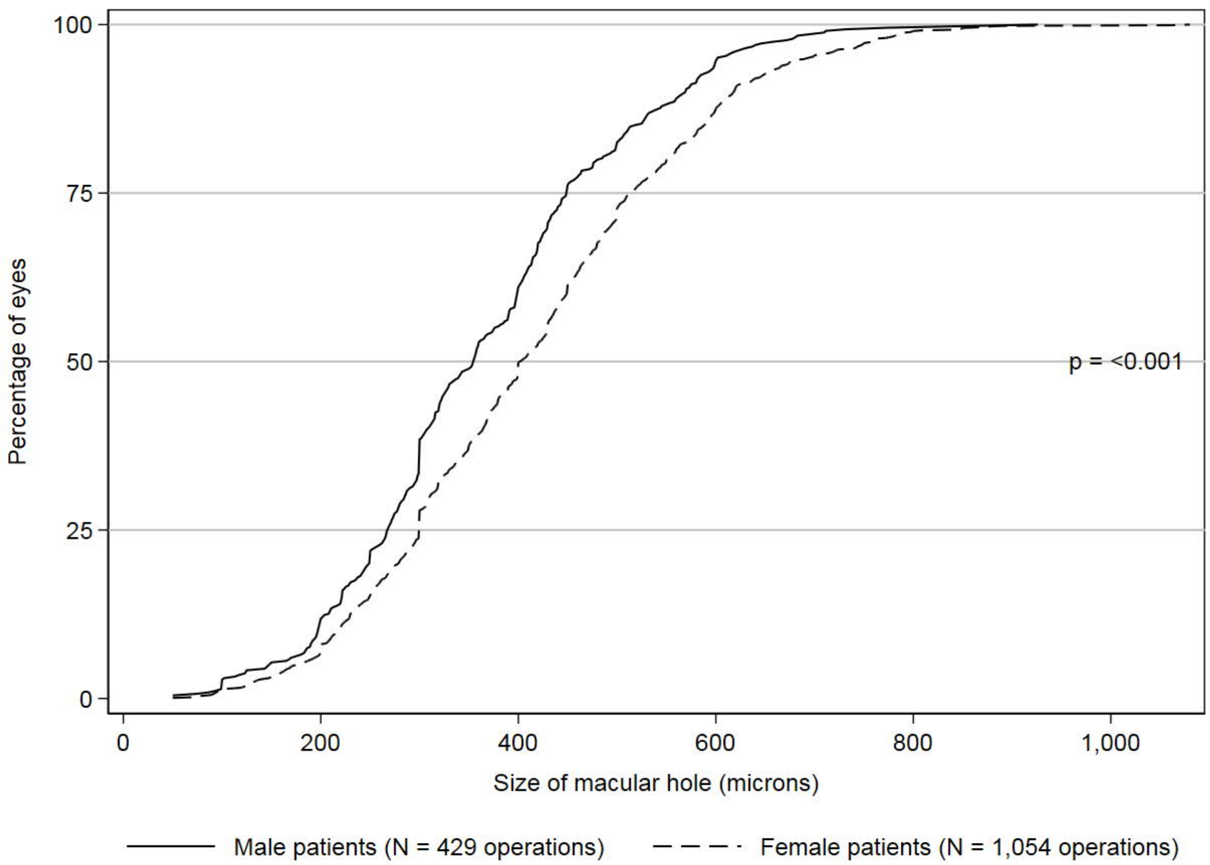
Cumulative frequency of macular hole diameter by the patients' gender, N = 1,483 primary macular hole operations.

Figure 1b:

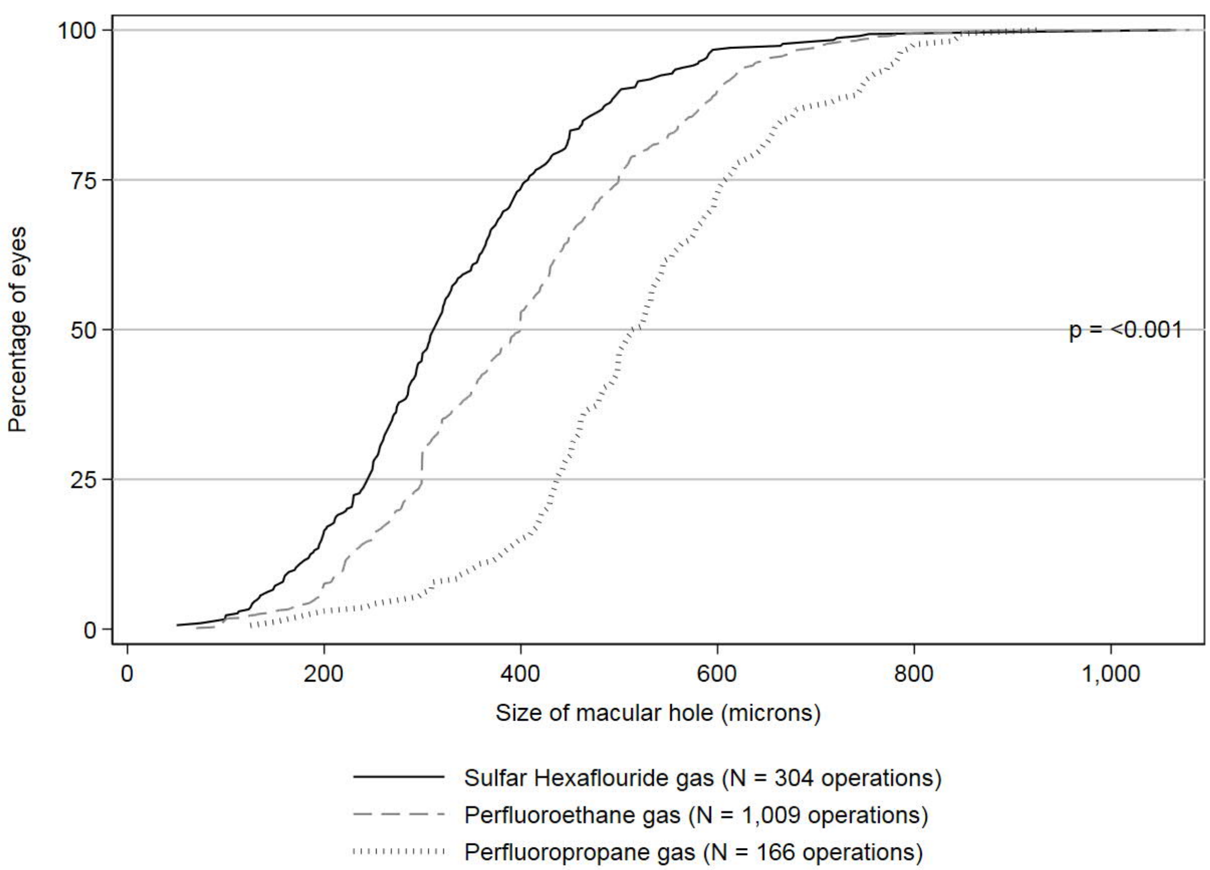
Cumulative frequency of macular hole diameter and ocular tamponade, N = 1,477 primary macular hole operations. Four operations that used air tamponade not included.

Figure 2:

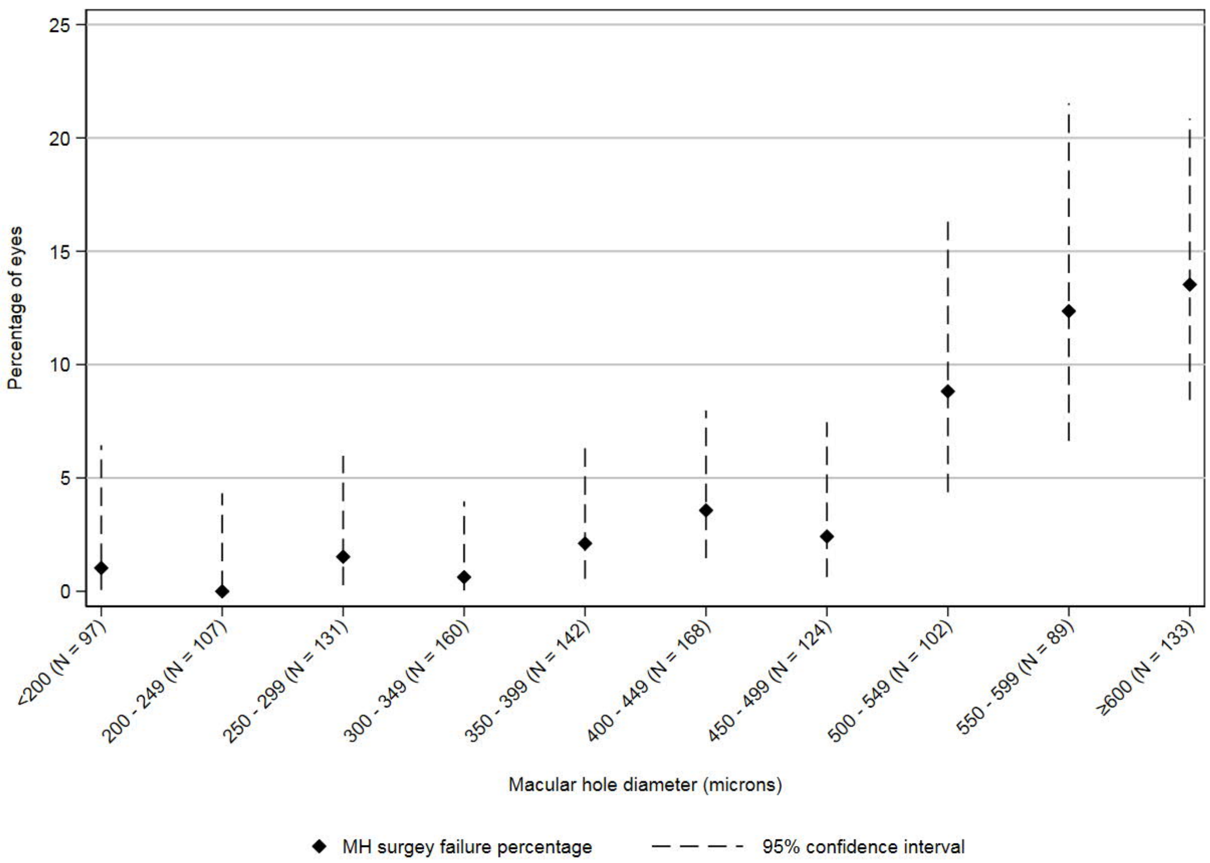
Macular hole surgery failed closure rates with 95% confidence intervals for 50 micron increments of the hole diameter, N = 1,253 primary macular hole operations with a known surgical outcome.



Percentage of eyes
100
75
50
25
0
p = <0.001
0
200
400
600
800
1,000
Size of macular hole (microns)
Male patients (N = 429 operations)
Female patients (N = 1,054 operations)



Percentage of eyes
100
75
50
25
0
p = <0.001
0
200
400
600
800
1,000
Size of macular hole (microns)
Sulfar Hexaflouride gas (N = 304 operations)
Perfluoroethane gas (N = 1,009 operations)
Perfluoropropane gas (N = 166 operations)



25
20
15
10
5
0
Percentage of eyes
<200 (N = 97)
200 - 249 (N = 107)
250 - 299 (N = 131)
300 - 349 (N = 160)
350 - 399 (N = 142)
400 - 449 (N = 168)
450 - 499 (N = 124)
500 - 549 (N = 102)
550 - 599 (N = 89)
≥600 (N = 133)
Macular hole diameter (microns)
MH surgey failure percentage
95% confidence interval

Table 1: Patient demographics

	Males	Females	Overall	p - value
N	**429**	**1,054**	**1,483**	**-**
Age at surgery (years)				
Median	72	69	70	
Mean	71.7	68.9	69.7	<0.001
Range	19 - 92	33 - 95	19 - 95	
Preoperative logMAR equivalent VA				
Median	0.78	0.78	0.78	
Mean	0.86	0.95	0.92	<0.001
Range	0.18 - HM	0.18 - HM	0.18 - HM	
Number with CF	23 (5.4%)	103 (9.8%)	126 (8.5%)	
Number with HM	1 (0.2%)	8 (0.8%)	9 (0.6%)	
Size of hole (microns)				
Median	355	402	394	
Mean	366.3	414.8	400.8	<0.001
Range	50 - 926	50 – 1,080	50 – 1,080	
Duration of symptoms (n,%)				
Duration known	189 (44.1)	543 (51.5)	732 (49.4)	0.009
Duration not known	240 (55.9)	511 (48.5)	751 (50.6)	
When known (months)				
Median	3	4	3	
Mean	4.6	4.9	4.8	0.422
Range	0 - 36	0 - 60	0 – 60	

Table 2: Univariate hypothesis testing of potential risk factors affecting visual success

	No Visual success	Visual success	Overall	p -value
N (row %)	**568 (53.8)**	**488 (46.2)**	**1,056**	**-**
Grade of operating surgeon				
Consultant	467 (53.2)	410 (46.8)	877	0.437
Trainee	101 (56.4)	78 (43.6)	179	
Gender				
Male	143 (47.0)	161 (53.0)	304	0.005
Female	425 (56.5)	327 (43.5)	752	
Age at surgery (years)				
<80	521 (53.0)	462 (47.0)	983	0.060
≥80	47 (64.4)	26 (35.6)	73	
Preoperative LogMAR (Snellen) VA				
>0.30 – 1.00 (>6/6 – 6/60)	261 (42.2)	357 (57.8)	618	<0.001
>1.00 - <CF (>6/60 - <CF)	223 (66.2)	114 (33.8)	337	
CF – NPL	84 (83.2)	17 (16.8)	101	
Size of hole (microns)				
<300	97 (36.7)	167 (63.3)	264	<0.001
300 - 399	126 (47.7)	138 (52.3)	264	
400 - 499	146 (55.1)	119 (44.9)	265	
500 - 599	105 (67.7)	50 (32.3)	155	
≥600	94 (87.0)	14 (13.0)	108	
Duration of symptoms				
<4 months	134 (44.2)	169 (55.8)	303	<0.001
4 or 5 months	57 (59.4)	39 (40.6)	96	
≥6 months	105 (66.5)	53 (33.5)	158	
Unknown	272 (54.5)	227 (45.5)	499	
Vitreoretinal attachment				
Attached with traction	157 (56.9)	119 (43.1)	276	0.350
Detached from fovea	215 (50.6)	210 (49.4)	425	
Complete PVD	60 (53.6)	52 (46.4)	112	
Not recorded	136 (56.0)	107 (44.0)	243	

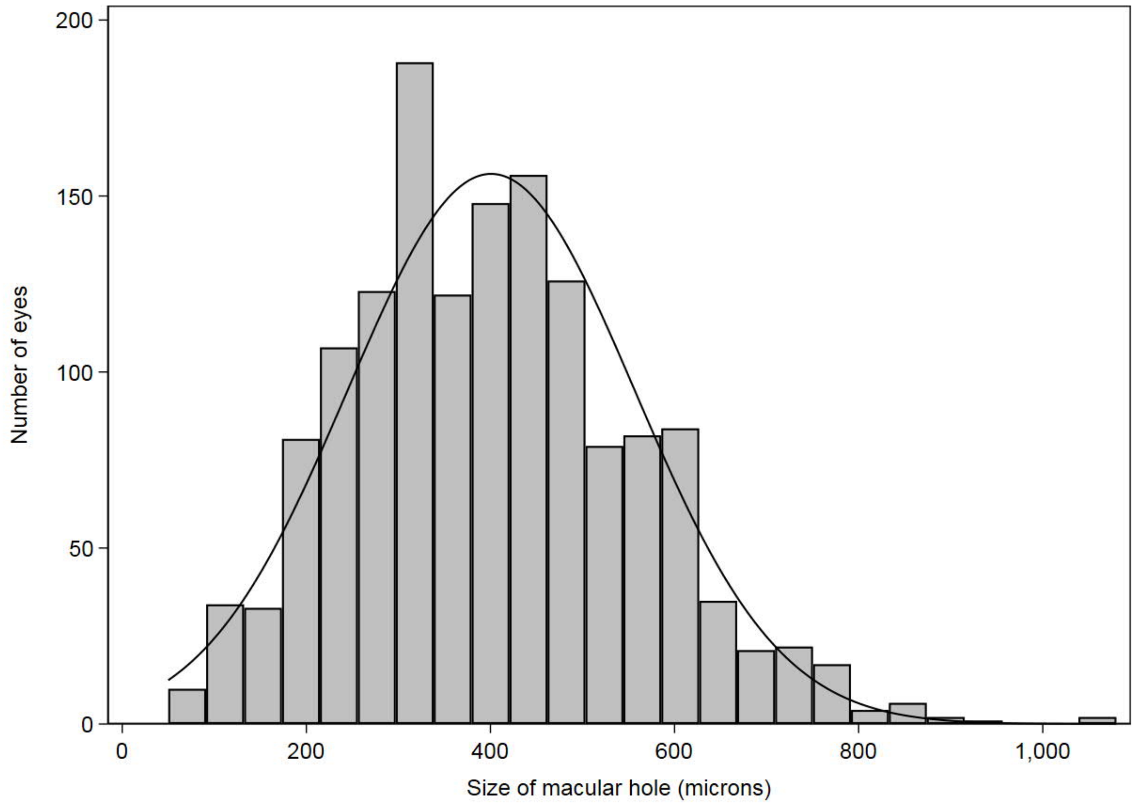
Lens status at time of surgery				
No cataract surgery	132 (53.4)	115 (46.6)	247	
Pseudophakic	83 (50.9)	80 (49.1)	163	0.690
Combined MH & cataract surgery	353 (54.6)	293 (45.4)	646	
Presence of AMD				
No	535 (52.7)	480 (47.3)	1,015	<0.001
Yes	33 (80.5)	8 (19.5)	41	
Ocular tamponade used				
Perfluoroethane gas	391 (53.4)	341 (46.6)	732	
Perfluoropropane gas	87 (66.9)	43 (33.1)	130	0.001
Sulpha hexafluoride gas	90 (46.4)	104 (53.6)	194	
Internal limiting membrane peeling				
Complete	529 (53.1)	467 (46.9)	996	
Incomplete	16 (76.2)	5 (23.8)	21	0.089
Not recorded	23 (59.0)	16 (41.0)	39	
Post-surgery posturing				
Prone	453 (54.0)	386 (46.0)	839	0.793
Not prone	115 (53.0)	102 (47.0)	217	

Table 3: Visual success model output, model AUC = 71.72%

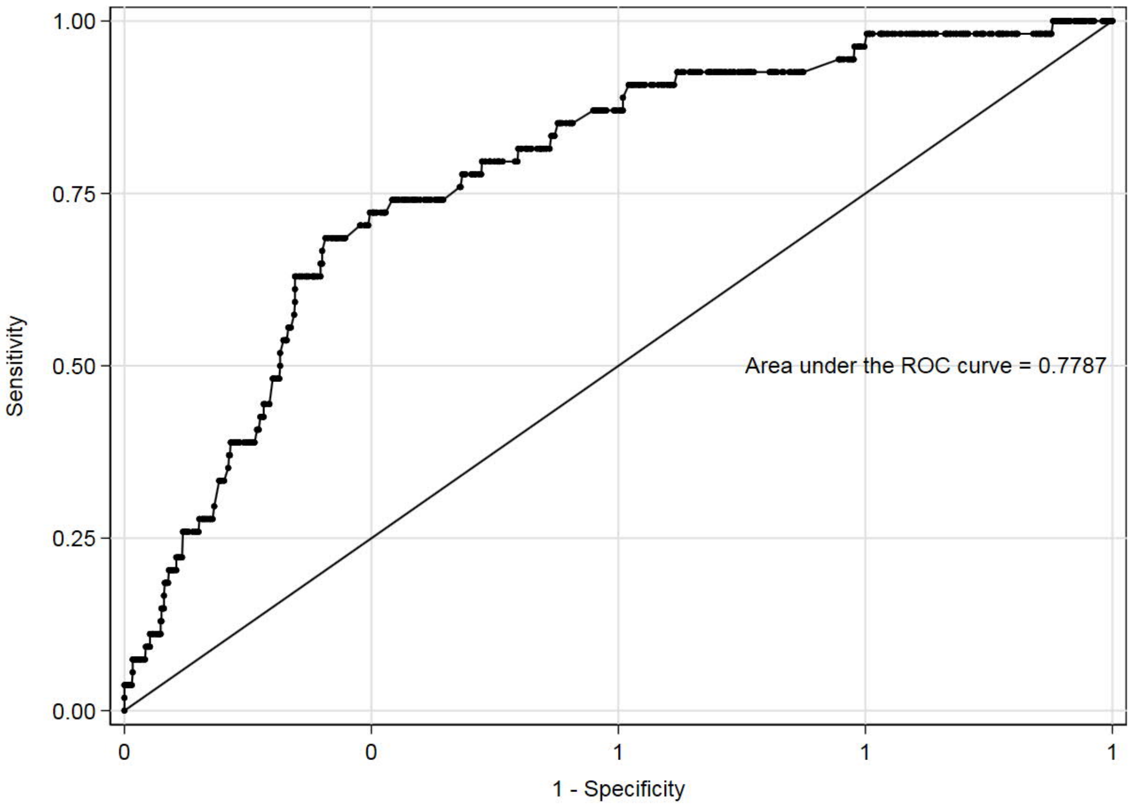
	Odds ratio	**Coefficient**	**p-value**	**95% CI for the odds ratio**	**Median follow up (months)**
Constant	3.112	1.134	<0.001	2.076 to 4.678	N/A
Preoperative logMAR (Snellen) VA					
>0.30 – 1.00 (>6/6 – 6/60)	REF	REF	N/A	N/A	2.7
>1.00 - <CF (>6/60 - <CF)	0.513	-0.667	<0.001	0.354 to 0.743	2.8
CF – NPL	0.224	-1.497	0.001	0.092 to 0.543	2.0
Size of hole (microns)					
<300	REF	REF	N/A	N/A	2.5
300 - 399	0.647	-0.436	0.039	0.428 to 0.978	2.8
400 - 499	0.571	-0.560	0.036	0.339 to 0.963	2.8
500 - 599	0.375	-0.980	<0.001	0.223 to 0.631	2.8
≥600	0.139	-1.976	<0.001	0.058 to 0.333	2.9
Duration of symptoms					
<4 months	REF	REF	N/A	N/A	2.9
4 or 5 months	0.546	-0.604	0.117	0.257 to 1.164	3.1
≥6 months	0.493	-0.707	0.018	0.275 to 0.885	2.8
Not known	0.669	-0.403	0.073	0.431 to 1.038	2.6
Presence of AMD					
No	REF	REF	N/A	N/A	2.7
Yes	0.206	-1.579	<0.001	0.104 to 0.409	2.9

Supplementary Data Steel et al.

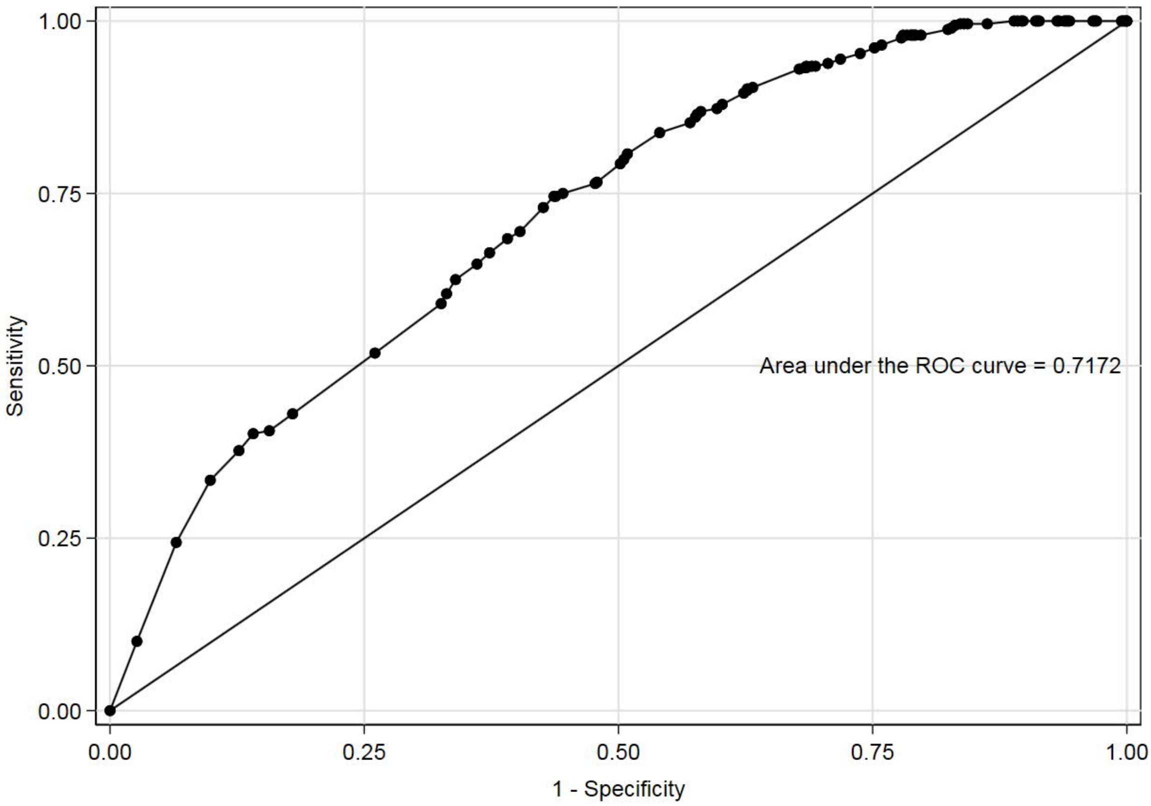
Supplementary Figure 1: Histogram of macular hole diameter for 1,483 primary macular hole operations.



Supplementary Figure 2: Receiver operator curve for macular hole diameter and failed hole closures, N = 1,253 primary macular hole operations with a known surgical outcome.



Supplementary Figure 3: Receiver operator curve for the visual success model, N = 1,058 successfully closed primary macular hole operations in eyes with ≥1 month follow up.



Supplementary table 1: Macular hole diameter and use of ocular tamponade

	Hole diameter (microns)			
Tamponade	**N**	**mean**	**Median**	**Range**
Air	4	98	89	50 - 164
Sulphur hexafluoride gas	304	333.5	312	50 – 1,061
Perfluoroethane gas	1,009	401.5	400	70 – 1,080
Perfluoropropane gas	166	526.5	518	125 - 926
Overall	**1,483**	**400.8**	**394**	**50 – 1,080**

Supplementary table 2: Anatomical failure

N (row %)	Failed closure	Successful closure	Overall	p -value
N	**54 (4.3)**	**1,199 (95.7)**	**1,253**	**-**
Size of hole (microns)				
<300	3 (0.9)	332 (99.1)	335	
300 - 399	4 (1.3)	298 (98.7)	302	
400 - 499	9 (3.1)	283 (96.9)	292	<0.001
500 - 599	20 (10.5)	171 (89.5)	191	
≥600	18 (13.5)	115 (86.5)	133	
Vitreoretinal attachment				
Attached with traction	11 (3.4)	309 (96.6)	320	
Detached from fovea	28 (5.8)	451 (94.2)	479	0.215
Complete PVD	4 (3.1)	127 (96.9)	131	
Not recorded	11 (3.4)	312 (96.6)	323	
Vitrectomy gauge				
23 gauge	31 (4.9)	596 (95.1)	627	
25 gauge	14 (3.1)	434 (96.9)	448	0.476
27 gauge	3 (5.9)	48 (94.1)	51	
Not recorded	6 (4.7)	121 (95.3)	127	
Ocular tamponade used				
Perfluoroethane gas	33 (4.0)	798 (96.0)	831	
Perfluoropropane gas	11 (7.5)	135 (92.5)	146	0.125
Sulpha hexafluoride gas	10 (3.7)	262 (96.3)	272	
Internal limiting membrane peeling				
Complete	48 (4.1)	1,131 (95.9)	1,179	
Incomplete	5 (17.9)	23 (82.1)	28	0.001
Not recorded	1 (2.2)	45 (97.8)	46	
Post-surgery posturing				
Prone	37 (3.8)	945 (96.2)	982	0.072
Not prone	17 (6.3)	254 (93.7)	271	
Holes <500 microns				
Prone	11 (1.5)	715 (98.5)	726	0.359
Not prone	5 (2.5)	198 (97.5)	203	
Holes ≥500 microns				
Prone	26 (10.2)	230 (89.8)	256	0.088
Not prone	12 (17.6)	56 (82.4)	68	

Supplementary table 3: The percentages of eyes with a specified postoperative visual acuity according to their preoperative visual acuity, results presented are row percentages.

Row %	**Postoperative VA**			
Preoperative VA	**≤0.30**	**0.31 – 1.00**	**1.01 – 1.80**	**CF or HM**
≤0.30 (N = 19)	84.2	15.8	0.0	0.0
0.31 – 1.00 (N = 621)	57.8	41.5	0.6	0.0
1.01 – 1.80 (N = 337)	33.8	60.2	5.0	0.9
CF or HM (N = 101)	16.8	66.3	11.9	5.0
Overall (N = 1,078)	46.9	49.3	3.1	0.7
Follow up time				
N	506 (46.9%)	531 (49.3%)	33 (3.1%)	8 (0.7%)
Median (months)	2.9	2.5	2.7	2.1
Range	1.0 months – 2.0 years	1.0 months – 2.4 years	1.2 months – 1.6 years	1.0 months – 0.9 years