Original Article

# A novel standardized reproducible method to calculate the area of internal limiting membrane peeled intra-operatively in macular hole surgery by using a video overlay—A long-term study in cases of idiopathic macular holes

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**Purpose:** To calculate AIP and to find correlation between hole closure pattern with AIP in idiopathic full thickness macular hole (FTMH) cases. **Methods:** In this prospective, non-randomized, interventional single blind study, 105 eyes of symptomatic FTMH (<6 month duration) were operated. Minimal diameter of macular hole (MDMH) was calculated on OCT, divided into Group I (>400μ, *n* = 75) and Group II (<400μ, *n* = 30). 23G vitrectomy with ILM peeling and gas injection were done in all and recorded. Final area of ILM peeled (AIP) was calculated using Adobe Photoshop CS2 (PSD format) in disc diameters (DD) from still frame. Follow up was done at 6 monthly interval up to a maximum of 5 years after surgery. **Results:** Macular holes were closed in 92.38% eyes. In Group I, mean pre-operative BCVA was 1.14 ± 0.39 log MAR and was improved to 0.79 ± 0.26 log MAR post-operatively at 6 months. In Group II, mean pre-operative BCVA was 0.95 ± 0.44 log MAR and was improved to 0.60 ± 0.24 log MAR after surgery. When AIP was more than 3DD, Type I and Type II closure were 72.77% and 27.27% in Group I (*P* value <0.01) and 84.21% and 15.79% in Group II (*P* value <0.01). **Conclusion:** AIP can be calculated using Adobe Photoshop CS2. Type I closure was significantly high with AIP >3DD in both groups. Intra-operatively using video overlay, surgeons can increase the diameter of AIP to get better closure pattern.

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The vast majority of macular holes are idiopathic in nature (prevalence - 3.3 per 1000).[1] Vitreous traction at the vitreofoveal interface (both antero-posterior and tangential traction) is the major pathogenic mechanism in the formation of full-thickness macular holes.[2] Gass believed that tangential traction caused by shrinkage of perifoveal vitreous cortex was responsible for idiopathic macular hole formation and staged it accordingly.[3,4] Data based on Optical Coherence Tomography (OCT) has supported Gass' original hypothesis attributing macular hole to vitreo-foveal traction and an OCT based classification were developed.[5,6] This theory has been additionally reinforced by successful treatments of macular hole with cortical vitreous peeling.[7] The proposed mechanisms seem to be contradicted by a number of patients in which a macular hole develops after a complete posterior vitreous detachment or even after Pars Plana Vitrectomy (PPV).[8,9]

Classic macular hole surgery consisted of vitrectomy with posterior vitreous cortex separation to relieve antero-posterior and centrifugal tangential traction, followed by intraocular gas tamponade at the end of surgery, to promote retinal reattachment by virtue of its surface tension and facilitating flattening and reposition of macular hole edges.

But during the past decade, focus has especially shifted on internal limiting membrane (ILM) peeling as an adjuvant therapy to ensure thorough removal of any tangential tractional components including any residual cortical vitreous and to increase centripetal mobilization of retinal tissue to ensure closure. Brooks HL Jr showed primary anatomic closure was achieved in 82% in non-ILM peeling group vs 100% in ILM peeling group.[10] Kumagai K *et al*. also showed that closure rate significantly improved from 81% in non-ILM peeling group to 92% with ILM peeling group.[11] Brilliant Blue G (BBG), has high affinity to ILM like ICG, but with minimal toxicity.[12] Shinodo H *et al*. mentioned that the standard recommendation was to peel ILM of around 2 disc diameter (DD) in size, centering macular hole.[13]

Post-operatively, macular hole closure pattern on OCT can be of two types—Type I closure where macular hole is closed without any foveal neurosensory retinal defect, and Type II closure, where macular hole is closed with foveal neurosensory retinal defect.[14,15] In study done by Kang SW *et al*., Type I closure was 61.3% and Type II closure was 38.7%.[14] Macular hole is considered as open when there is persistent defect in foveal neurosensory retina with surrounding serous detachment at its base.



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Recently, Steel D. H *et al*. calculated the ILM peeled area from intra-operative images in square millimetre and showed that theILM-peeled area has a significant effect on changes in retinal topography and postoperative visual acuity in macular hole surgery.[16] But this method was not a logical reproducible way to assess AIP which can be applied by other surgeons during surgery.

Bae K *et al*. highlighted that large extent of ILM peeling during macular hole surgery is beneficial with respect to the reduction of metamorphopsia and they further showed that peeling of either 0.75DD or 1.5DD, in a predetermined way, had no effect on pattern of hole closure.[17]

So, the previous studies did not highlighted the fact that how much area of ILM needs to be peeled, in relation to the pre-operative macular hole diameter. The purpose of this study was to find out the correlation between macular hole closure pattern on postoperative OCT with the area of ILM peeled as well as a logical, standardized, reproducible method to calculate the area of Internal Limiting Membrane (ILM) peeled during macular hole surgery.

## Methods

In this prospective, single blind, interventional study, 105 eyes of 105 patients, with symptomatic idiopathic FTMH, with less than 6 months duration, had been operated by three vitreoretinal surgeons in a tertiary eye care hospital of eastern part of India, from April 2008 to September 2011 and followed up till December 2016. The present study strictly adhered to the tenets of Declaration of Helsinki, and informed consent was obtained from every patient. Approval from Institutional Review Board was taken.. Triamcinolone acetonide assisted suture less 23G vitrectomy were performed in all cases, along with induction of posterior vitreous detachment and its removal. Internal limiting membrane (ILM) stained with BBG dye and peeled using either 23G end-grasping forceps or ILM forceps, followed by total fluid air exchange. Perfluoropropane ($C_3F_8$) gas in iso-expansile concentration (12%) was used as tamponade. All surgeries were video recorded. Prone position was maintained for 7 days post-operatively. Post-operative follow-up was varied from 6 months in all cases to maximum of 60 months.

Included cases were idiopathic full thickness macular holes of all stages (Stage II, III, and IV) of less than 6-month duration.

The exclusion criteria were:

1) Macular holes secondary to trauma, chronic cystoid macular edema,
2) Those associated with epiretinal membrane,
3) Macular holes with symptoms longer than 6 months and
4) Where the disc diameter was considered small (less than 1.5 mm) or large (greater than 1.9 mm) [We measured the vertical disc diameter by adjusting the slit lamp beam height to the edges of the disc, while viewing the disc with a +78D lens and multiplying the measured value with the magnification factor 1.2.[18-20] The Disc Damage Likelihood Scale (DDLS) method, developed by Bayer *et al*.[19] and Spaeth *et al*.[20] divides discs into three sizes, small (<1.5 mm), medium (1.5–2.0 mm), and large (>2.0 mm). However, according to the Crowston *et al*., a disc is considered small if the vertical diameter is <1.3 mm, medium 1.4–1.7 mm, large >1.8 mm.[18] As Indian discs are a bit larger so for Indian eyes disc is small if <1.5 mm, medium if 1.5–1.9 mm and large if >1.9 mm.].

### Parameters evaluated

1. Area of ILM Peeled (AIP)—A novel technique was introduced to calculate area of ILM peeled (AIP). AIP was calculated from the recorded video. Still frame of the final AIP had been taken using Adobe photoshop CS2 (in PSD format). Final AIP, centered on the macular hole was calculated according to the longest disc diameter (DD) using three equidistant concentric rings with enlarging diameter (1DD, 2DD, and 3DD). Depending on whether the margin of ILM peeled area was covering the 3DD circle in at least three quadrants or not, cases were then divided into two groups—more than 3DD (>3DD) and less than 3DD (<3DD). AIP had been measured in the following way: Three equidistant concentric circles were made in Adobe photoshop CS2 in PSD format and smallest circle was fitted according to the longest disc diameter in the final still frame of the ILM peeling from the recorded video. Now these three circles were shifted to the ILM peeled area to note whether the margin of the ILM peeled area was crossing the outermost circle in at least in three quadrants or not [Fig. 1]
2. Pre-operative Minimal diameters of macular holes (MDMH)—It was measured on Spectral Domain OCT using calipers, divided into two groups–Group I (with MDMH >400μ) and Group II (with MDMH <400μ) by an independent observer and it's absolute value was not disclosed to the surgeons, prior to surgery
3. Post-operative macular hole closure pattern on SD-OCT—performed in all either after 7 days or 14 days (if closure pattern was certain on 7$^{th}$ day OCT) and it was noted if it was a Type I closure, Type II closure or open. For all open macular holes, repeat ILM peeling with fluid air exchange with long acting C3F8 gas injection in isoexpansile concentration (12%) done

Intra-operative AIP was calculated in all cases using the method described above. Relation between per operative

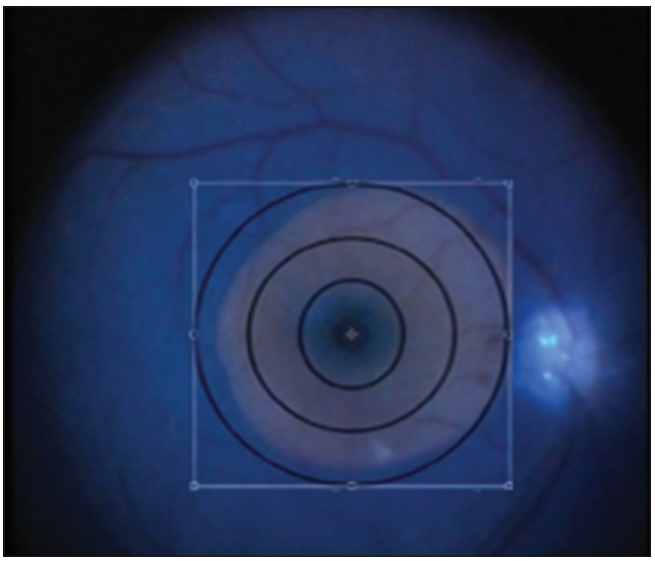

**Figure 1:** Three equidistant concentric circles, made in Adobe photoshop CS2 in PSD format

AIP and post-operative macular hole closure pattern were statistically analyzed between the two groups.

## Results

Out of total 105 consecutive patients, 75 eyes of 75 patients were enrolled in Group I and 30 eyes of 30 patients were enrolled in Group II by an independent observer. Male:Female ratio was 48:57. FTMHs were closed on post-operative SD-OCT in 97/105 (92.38%) eyes. In Group I, closure rate was 67/75 (89.33%) eyes and in Group II, it was 30/30 (100%) eyes. Overall pre and postoperative mean best corrected visual acuity (BCVA) were 1.09 ± 0.41 and 0.73 ± 0.26 logMAR, respectively. In Group I, mean preoperative BCVA was 1.14 ± 0.39 logMAR and improved to 0.79 ± 0.26 logMAR postoperatively. In Group II, mean preoperative BCVA was 0.95 ± 0.44 logMAR and improved to 0.60 ± 0.24 log MAR after surgery.

In Group I, mean MDMH was 618.45 ± 143.45 μ and in Group II, it was 273.53 ± 64.64 μ. The closure patterns (whether Type I or Type II) were variable according to the area of ILM peeled and pre-operative MDMH [Table 1].

Combined phacoemulsification with IOL implantation and macular hole surgery done in twenty patients in Group I and 5 patients in Group II. 25 patients in Group I and 9 patients in Group II were left phakic. Thirty patients in Group I and 16 patients in Group II were already pseudophakic.

Although we used 23 gauze vitrectomy system as a minimally invasive suture less procedure, we used sutures to close the leaking ports at the end of surgery. We sutured one port in four eyes and two ports in three eyes. In no case, all the three ports needed sutures.

In Group I, AIP was more than 3DD in 48 eyes and less than 3DD in 27 eyes. When AIP was more than 3DD in size, Type I and Type II closure were seen in 32/44 (72.73%) eyes and 12/44 (27.27%) eyes respectively (*P* value <0.01, statistically significant) [Fig. 2]. In four eyes, macular hole remained open in spite of AIP >3DD in size. But in this group, when we peeled ILM of less than 3DD in size, Type I and Type II closure were seen in 8/23 (34.78%) eyes and 15/23 (65.22%) eyes respectively (*P* value <0.08, but >0.05, statistically less significant). In four eyes, macular hole remained open in this group with AIP less than 3DD in size.

In Group II, AIP was more than 3DD in 19 eyes and less than 3DD in 11 eyes. When AIP was more than 3DD in size in Group II, Type I and Type II closure were seen in 16/19 (84.21%) and 3/19 (15.79%) eyes (*P* value <0.01, statistically significant) [Fig. 3]. But in this group when we peeled ILM of less than 3DD in size, Type I closure was noted in 8/11 (72.73%) and Type II closure pattern was in 3/11 (27.27%) eyes (*P* value was statistically not significant). In none of the cases in Group II, macular hole was open after primary surgery.

In our study, macular hole remained open in 8/75 patients of Group I after intervention. In 4 out 8 patients with open macular hole, AIP was >3DD and in rest of 4 patients, AIP was <3 DD in size. For all open macular holes, repeat ILM peeling with fluid air exchange with long acting C3F8 gas injection in isoexpansile concentration (12%) done. 5/8 open macular holes were closed after re-surgery, although these cases were not considered as the primary closure. 3/8 open macular holes remained open even after re-surgery. No more repeat procedure was performed in these three eyes.

Only one case in Group I developed retinal detachment after surgery.

**Table 1: Shows relationship between Area of ILM Peeled (AIP) and Macular hole closure pattern, considering pre-operative Minimal Diameter of Macular Hole (MDMH)**

| Group | MDMH | AIP | Type I closure | Type II closure | Open hole | *P* |
|---|---|---|---|---|---|---|
| I | >400μ | >3DD | 32 | 12 | 4 | <0.01 |
| I | >400μ | <3DD | 8 | 15 | 4 | <0.08, but >0.05 |
| II | <400μ | >3DD | 16 | 3 | 0 | <0.01 |
| II | <400μ | <3DD | 8 | 3 | 0 | Not significant |

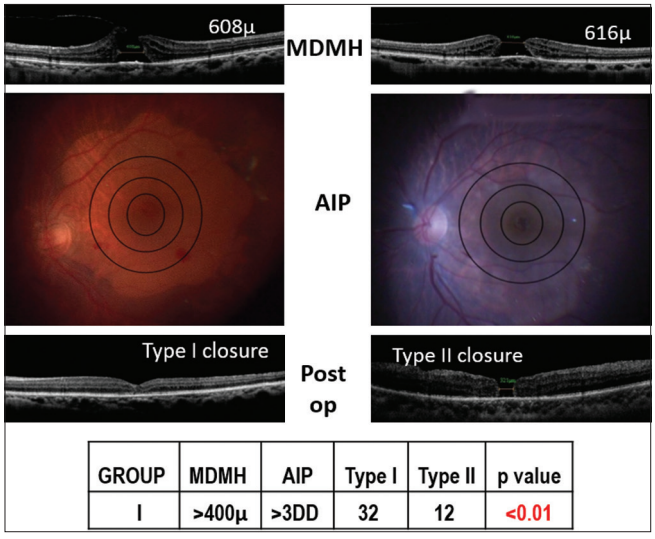


**Figure 2:** In Group I, *P* value was statistically significant when AIP was more than 3DD in size

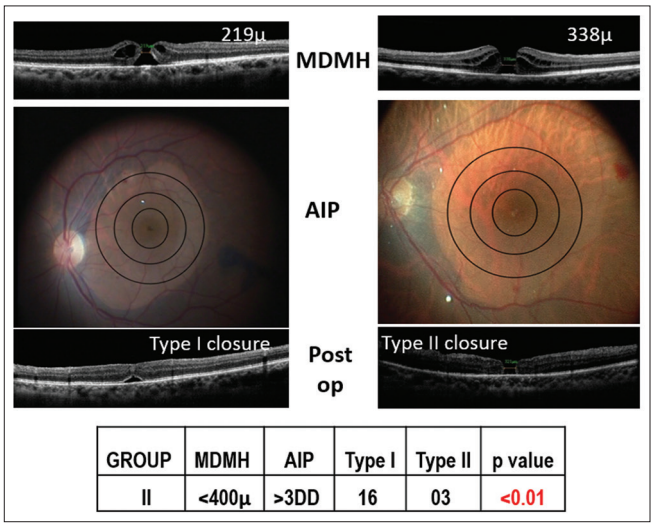


**Figure 3:** In Group II, *P* value was statistically significant when AIP was more than 3DD in size

All patients underwent at least 6-month follow up. 46.67% (49/105 patients, Group I = 29, Group II = 20) completed 12 months follow up. 23.81% (25/105 patients, Group I = 14, Group II = 11) completed 24 months follow up. 17.14% (18/105 patients, Group I = 12, Group II = 6) completed 36months follow up and 11.43% (12/105 patients, Group I = 8, Group II = 4) completed 42 months follow up. Only 7.62% (8/105 patients, Group I = 5, Group II = 3) completed 5 years follow up. Visual improvements in both groups are depicted in the chart [Fig. 4].

## Discussion

Reports of more than 90% primary closure have appeared in the literature claiming that ILM peeling was the single most important variable. Smiddy WE *et al*. highlighted the fact that dissection of the ILM may provide the predominant stimulus for glial proliferation which has a role in the closure of macular hole in large extent ILM peeling cases.[21]

The idea to calculate the ILM peeled area came to our mind from our previous observations that in small sized macular hole of less than 400μ in diameter, Type I closure was not happening in all, but even in large sized macular hole of more than 400μ in diameter, Type I closure was possible. This must be related to the relative degree of centrifugal traction, which is released by more ILM peeling, thereby causing more mobilization of peri-hole retinal tissue. In our study, the measurement of AIP in longest disc diameter was possible by using Adobe Photoshop CS2 in PSD format by three equidistant concentric circle of enlarging diameter (i.e., 1DD, 2DD, and 3DD). Often, ILM peeled area is not perfectly circular; many a times, AIP may be oval, irregular or oblong shaped. So, we decided to measure the size of AIP by taking the still frame of final AIP from the recorded video and the margin of this final AIP should cover the 3DD circle margin in at least 3 quadrants, centering macular hole.

Pre-operatively, minimal diameter of the macular holes were measured as these margins have highest propensity to appose.

In the literature, the incidence of Type I closure was 61.3% and Type II closure was 38.7%.[14] In present study, we observed that when ILM was peeled more than 3DD in macular holes more than 400μ size (Group I), type I closure was significantly higher ($P < 0.01$) than type II closure. But in this group, when AIP was less than 3DD, type II closure was more common than type I. However, this was statically less significant ($P$ value was <0.08, but >0.05).

Similarly, in Group II with MDMH <400μ in size, when AIP was more than 3DD in size, Type I and Type II closure were 84.21% and 15.79% respectively ($P < 0.01$, statistically significant); but when AIP was less than 3DD in size, incidence of Type I closure was only 72.73% and Type II closure pattern was 27.27% which was statistically not significant. The present study can be regarded as a pilot study, that highlights a logical reproducible method to measure area of ILM peeled and related the association between intra-operative ILM peeled area and post-operative pattern of macular hole closure.

Hence, we recommend AIP of 3DD or more to achieve post-operative type I closure. In the present study, macular hole closure was seen in 92.38% eyes. Similar results were seen by Shinodo H *et al*., who reported macular hole closure in 96% eyes.[13] However, in that study, pattern of hole closure was not evaluated, and the author recommended AIP of 2DD. In the present study, we find that 2DD of AIP leads to hole closure, but more than 3DD of AIP results in high possibility of type I closure.

The application of this three equidistant concentric circle, made in Adobe Photoshop, is that we can use it intra-operatively as a video overlay. An online switcher is required for chroma keying and mixing using two analog inputs, one from camera microscope as live video and another from computer as video overlay. The final analog signal input will go to the video recorder so that the surgeon can use this video overlay intra-operatively to calculate ILM peeled area in respect to the disc diameter. The practical utility of this video overlay guided ILM peeling is that surgeon can continuously notice the ILM peeled area intra operatively in the TV panel, centering the macular hole and if it is seen that the margin of AIP is not crossing the outermost circle of the overlay, then surgeon can enlarge the area of ILM peeled by peeling more ILM [Fig. 5], specially for large macular holes to ensure better closure pattern. For this assessment a continuous meticulous monitoring is required.

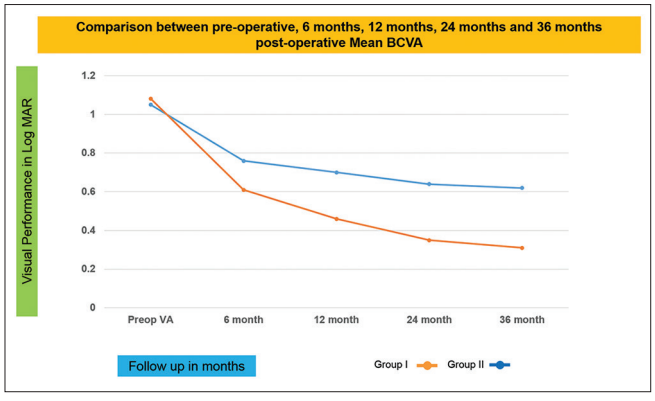


**Figure 4:** Comparative visual improvements in both groups between pre-operative, 6 months, 12 months, 24 months and 36 months

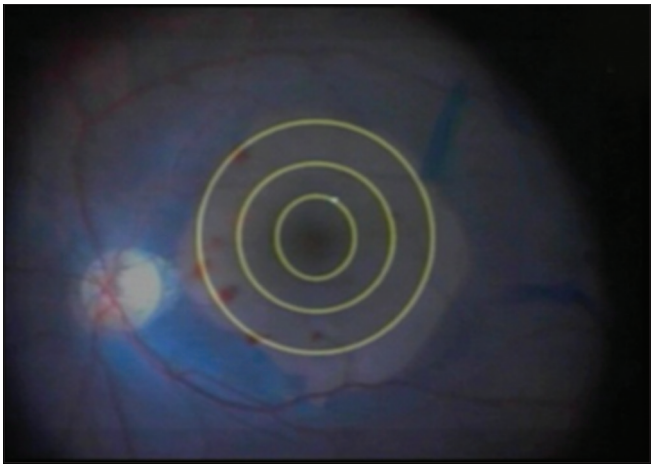

**Figure 5:** Intra-operatively, surgeon can enlarge the area of ILM peeled by using video overlay

As majority of the patients in our study were having large sized macular hole with relatively poorer visual recovery, long-term follow up was less. Although all patients completed 6-month follow up, but only 46.67% (49/105) patients completed 1 year follow up and 23.81% completed 2 years follow up. Five years follow up was extremely low, only 7.62% (8/105 patients). Visual improvement was evident mainly for the initial 36 months in both groups among the patients who did follow up, though there was a steep improvement in vision noted in first 6 months.

## Conclusion

AIP can be calculated using Adobe Photoshop CS2. As there is no definite standard method to calculate the AIP, this is a novel method to measure how much area of ILM has been peeled. We have seen Type I closure was significantly higher when AIP was more than 3DD in size in both groups. Intra-operatively using the video overlay of 3 equidistant concentric rings, surgeon can increase the diameter of ILM peeled area, according to the pre-operative minimal diameter of macular hole, to ensure a better closure pattern postoperatively.

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### Conflicts of interest

There are no conflicts of interest.

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