Idiopathic full thickness macular hole: natural history and pathogenesis

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Although full thickness macular holes (FTMH) were originally described in the last century, in relation to trauma,1–7 inflammation, and myopia,1–3 more recent clinical studies have shown that the vast majority are idiopathic4–16 and occur with a prevalence of 1/3300 usually in the 6th and 7th decades of life.7 Many clinical studies have implicated vitreous traction as the cause of idiopathic FTMH formation and it is now widely accepted that traction at the level of the vitreofoveal interface is the underlying mechanism.

Recent work by Kelly and Wendel17–18 and others19–28 has shown that surgical intervention in the form of vitrectomy, cortical vitreous peeling, and gas tamponade is beneficial in the majority of eyes with FTMH in promoting anatomical closure and foveal reapposition with subsequent visual improvement. In addition, these studies have proposed rigorous face down posturing in the postoperative period as an important factor in achieving improved anatomical results. In the light of the implications of surgical intervention and prolonged face down posturing for elderly patients, the natural history of FTMH has assumed great importance, in particular with respect to fellow eye involvement. The purpose of this review is to summarise the natural history, clinical staging, and pathogenesis of idiopathic FTMH.

Natural history and clinical staging

A number of studies in the 1970s and 1980s attempted to define the clinical characteristics and progression of macular holes. These were difficult to interpret owing to lack of consistency in the definitions used by investigators.9–12 In particular, studies investigating the nature of the “prehole” lesion proved controversial.

Morgan and Schatz15 suggested that involutinal thinning resulted in a depressed central area at the fovea which represented the prehole lesion, while others proposed that a foveal cyst10 12 13 occurred before hole formation. Several underlying mechanisms were implicated by these investigators, including degenerative macular thinning, degeneration of a macular cyst, intrinsic retinal pigment epithelium (RPE) disease, systemic vascular disorders, and hormonal influences.8–15 These early studies were retrospective in nature and consisted of lesions examined and defined by different clinicians. It was Gass and Johnson15–16 who described the yellow spot and ring as the prehole lesion, and the systematic clinical staging and evolution of idiopathic FTMH, based on detailed observation and follow up. They proposed that focal shrinkage of the cortical vitreous in the area of the fovea resulted in tangential tractional forces acting on the fovea. Their classification, with its subsequent revision, is that which is now most commonly used by clinicians and will now be described in detail.

THE ORIGINAL GASS CLASSIFICATION15 16

Stage 1—Foveolar detachment

This is also termed an “impending hole” and is characterised by progressive loss of the foveal depression, associated with the appearance of initially a yellow spot of approximately 100–150 µm at the fovea (stage 1a), later enlarging to a yellow ring (stage 1b). These changes were attributed to contraction of the prefoveal vitreous cortex with centripetally directed tangential force, leading to anterior displacement of the foveoretinal and greater visibility of the centrifugally displaced xanthophyll. In stage 1 lesions, the posterior vitreous cortex is attached and the retinal surface is intact without any evidence of hole or subretinal fluid cuff. The visual acuity at this stage is often reasonably good (20/20–20/60)15 16 22 and blurring and metamorphopsia are the primary complaints. These symptoms are the rule not the exception when a patient presents with involvement of the fellow eye but may be unnoticed in the initial eye, particularly if this is the non-dominant eye.

Stage 2—Early FTMH

Further traction results in the formation of a foveal hole or dehiscence associated with a cuff of subretinal fluid. At this stage, the posterior cortical vitreous is still attached at the fovea and, in many cases, radial tractional striae may be visible around the edges of the hole at the level of the inner retina and internal limiting membrane. In addition, intraretinal cystoid spaces appear around the edges of the hole. The visual acuity usually deteriorates to a level of 20/40–20/10015 16 and metamorphopsia increases. Two configurations may occur at stage 2:

(a) Centric: The full thickness tear begins at the centre of the fovea (umbo dehiscence) and expands in a symmetric fashion.

(b) Pericentric: A full thickness tear arises at an eccentric position in the fovea and extends in a “can opener” fashion to form a crescentic hole progressing to a “horseshoe” shaped hole and eventually, when the can opener is complete, to a round hole with a fully detached operculum of tissue suspended on the posterior vitreous cortex in the prefoveal plane. This configuration is typical in the majority of stage 2 FTMH (80–90%).

Stage 3—Fully developed FTMH without posterior vitreous detachment

With further enlargement of the hole, vitreofoveal separation occurs at the macula. The localised separation of the vitreous cortex is usually only detected because of the presence of the operculum suspended on it lying a short distance (between 100 and 500 µm) anterior to the retinal plane. The fully detached operculum, particularly in cases with more widespread vitreofoveal separation, becomes mobile and this may be detected with eye movements. Further enlargement of the hole was attributed by
Gass to passive forces resulting from elastic tissue forces within the retina. Stage 3 holes usually measure more than 350 µm and may occasionally reach a diameter of greater than 500 µm. In addition, as the hole enlarges, discrete white deposits appear on the surface of the RPE at the base of the hole, which represent nodular proliferations of RPE cells. In more long standing cases, a pigmented demarcation line at the level of the RPE may be seen surrounding the cuff of fluid and diminution of the striae and cystic changes may occur. Stage 3 holes are usually associated with acuity levels of 20/60–20/200,\(^{15,16}\) prominent metamorphopsia, and on occasions a pericentral positive scotoma.

**Stage 4—FTMH with posterior vitreous detachment**

In about 20% of cases, a full posterior vitreous detachment (PVD) occurs with the presence of a Weiss ring. The operculum can often be seen on the mobile posterior vitreous face in the vitreous cavity. In the majority of cases, little or no further enlargement of the hole occurs thereafter with little significant functional deterioration.

**THE REVISED GASS CLASSIFICATION**

In 1995 Gass reappraised his theory of macular hole formation.\(^{30}\) Initially, he had suggested that vitreotomy and peeling of the premacular posterior vitreous cortex might prevent stage 1 lesions from progressing.\(^{15,16}\) Although early surgical studies suggested that this was indeed the case,\(^{31–33}\) a randomised study subsequently proved inconclusive, when it was terminated before sufficient numbers had been recruited to reach statistical significance between the treatment and observation groups.\(^{34–36}\) Attention was then focused on whether vitreous peeling in established FTMH might result in hole closure and visual improvement. Kelly and Wendel\(^{17,18}\) and others\(^{19,20}\) have since demonstrated that the majority of established FTMH may be closed surgically using vitrectomy, posterior cortical vitreous peeling, and long acting intraocular gas tamponade, and that the majority of eyes demonstrate significant visual improvement. Indeed, in many cases, visual acuity may improve to near normal levels of between 20/20 and 20/60.\(^{17–20}\)

In the light of these results, in his recent reappraised theory, Gass suggested that the majority of FTMH arise from an umbo dehiscence without loss of foveal tissue. He hypothesised that the stage 1b lesion is caused by centrifugal displacement of xanthophyll associated with foveolar detachment, and following a retinal dehiscence at the umbo, by passive enlargement of the “occult” hole beneath the semiopaque, contracted vitreous cortex bridging the edges of the hole. Thus, at this stage, biomicroscopy cannot differentiate between an impending hole and an occult hole. Subsequently, a tear occurs in the contracted vitreous cortex overlying the occult hole, over the edge (pericentric/eccentric stage 2) of the occult hole and the hole becomes visible on biomicroscopy as a stage 2 lesion. Enlargement of the eccentric tear in a can opener fashion occurs to form a “pseudo-operculum” composed of vitreous collagen, giall tissue but no photoreceptors. In some cases, rapid and complete vitreofoveal separation occurs and the umbo dehiscence becomes immediately visible on biomicroscopy as a centric stage 2 lesion. With vitreofoveal separation, the FTMH evolves into a stage 3 and eventually a stage 4 hole when a full PVD develops.

**PROGRESSION AND TIME COURSE**

The progression from stage 1 to stage 2 and from stage 2 to stage 3 usually takes several weeks or months, although in some cases the lesion may remain static without progression at any of the stages described. In most patients it is difficult to establish with any certainty the exact duration of the lesion, as many stage 1 and some stage 2 lesions are asymptomatic, particularly if occurring in the first eye of the patient. In fact, very few lesions present at stage 1 and most patients only experience symptoms and attend for examination when a full thickness defect has become established at the fovea. Most patients with a first eye lesion usually only notice symptoms by coincidence, either after happening to cover the normal fellow eye, or when attending for routine refraction. In contrast, patients with a second eye lesion will often give an accurate account of the onset of symptoms and the duration of the lesion may be determined with greater certainty.

Johnson and Gass\(^{15}\) and Kokame \(\text{et al.}\)\(^{38}\) observed that approximately 66% of stage 1 lesions progressed to FTMH, somewhat higher estimates compared with those of 37% by Akiha \(\text{et al.}\)\(^{39}\) and 10.5% by Guyer \(\text{et al.}\).\(^{40}\) Hikichi \(\text{et al.}\) noted that approximately 67% of stage 2 holes progressed to stage 3 and approximately 30% to stage 4.\(^{16}\) More recently, Kim \(\text{et al.}\) reported the results of a randomised trial which included an observation arm for stage 2 holes.\(^{41}\) They found a 55% progression rate to stage 3 for centric stage 2 holes, compared with 100% for pericentric (can opener) holes, with an overall progression rate of all stage 2 holes to either stage 3 or 4 of 74%.

**SPONTANEOUS ARREST AND CLOSURE OF MACULAR HOLE LESIONS**

It is well recognised that 30–50% of stage 1a and 1b lesions will arrest or resolve spontaneously often with resolution symptoms in some eyes.\(^{15,16,29,36}\) In such cases, arrest usually occurs following vitreofoveal separation and a good visual acuity is a favourable prognostic indicator.\(^{29}\)

Gass has described the clinical features of arrested lesions.\(^{15}\) The fovea may have an entirely normal contour (Ar-A/B), or may demonstrate a residual small inner lamellar defect (Ar-C) or larger inner lamellar defect (Ar-D) often with an operculum on the separated vitreous face. In such cases, patients may notice the operculum as a small dark mobile object in the visual axis but the visual acuity is usually normal or near normal. In some patients, the operculum may cast a shadow onto the fovea, during slit lamp examination, which may be mistaken for a FTMH.

Spontaneous closure may also occur in a stage 2 or 3 lesion, although this is relatively rare, occurring in less than 10% of cases.\(^{15,16,40,42}\) Again this is usually associated with vitreofoveal separation in stage 2 holes and further vitreofoveal separation or a full PVD in stage 3 holes. The closed hole may demonstrate a virtually normal foveal reflex or a lamellar defect as described above and the visual acuity may recover to the 20/20–20/60 level. In the majority of cases, vitreofoveal separation with an operculum is seen and only a minority will develop a full PVD.

**EXAMINATION AND DIAGNOSIS**

Although impending holes and FTMHs may be confused with a number of other foveal and macular lesions,\(^{15,16,42,43}\) careful slit lamp biomicroscopy is usually sufficient to establish the diagnosis in the majority of cases. In particular, fundus contact lens examination should be performed in all cases where doubt exists. The Watzke–Allen test\(^{15}\) is also extremely useful in differentiating FTMHs from other lesions. In this test, a very narrow slit beam is projected with a 90 or 78 dioptre lens onto the fovea and the patient is asked to describe the line. Most patients with a stage 3 FTMH report a break in the central portion of the line (Watzke-Allen positive), whereas those with small holes (with a relatively intact foveal photoreceptor population) or other lesions associated with metamorphopsia may report
Incidence of macular hole in fellow eyes

Although FTMH is an important cause of central visual loss with a prevalence of 3.3 per 1000, the majority of patients have unilateral involvement at presentation and are able to continue with good visual function from the fellow eye. Thus, the risk to the fellow eye is an important factor for both patients and clinicians in determining whether surgical treatment of the first eye is pursued. In particular, the risks of surgery, anesthesia, and the postoperative posterior regimens have to be considered very carefully in older patients, especially if the risk to the normal fellow eye is low. In assessing the risk to a fellow eye very carefully in older patients, especially if the risk to the fellow eye is low. Thus, from the data available to date, it appears that in patients with a unilateral FTMH, the 5 year risk to a normal fellow eye may be 10–20%.

Pathogenesis of FTMH formation and histopathological studies

Several hypotheses for the pathogenesis of FTMH have been suggested including cystic foveal degeneration, thinning (Watzke–Allen negative). A more reliable test may be performed by projecting a 50 µm HeNe laser spot onto the centre of the suspected FTMH; the patient with a FTMH will not perceive the spot. In impending FTMH, early faint central foveal hyperfluorescence is seen at the fovea in some cases, while in others a normal angiogram may occur. In stage 2 holes, the central early hyperfluorescence is usually more pronounced and fades during the later stages of the run; however, in some cases no hyperfluorescence is observed. Therefore, fluorescein angiography cannot differentiate with any certainty between stage 1 and 2 lesions and clinical examination is often more reliable. In stage 3 and 4 lesions, the hyperfluorescence is more obvious and is frequently associated with changes at the RPE level which may also be seen biomicroscopically.

In our prospective fellow eye study outlined above, we demonstrated elevated tritan thresholds during colour contrast sensitivity (CCS) testing of apparently normal fellow eyes later develop FTMH may have reduced FERG responses. Although these data suggest that even an apparently normal fovea may in fact be subject to some degree of traction resulting in cone misalignment and malfunction before symptoms or signs of foveal traction become apparent, electrodiagnostic techniques have not proved to be particularly useful or feasible in general ophthalmic practice, in predicting fellow eyes at risk.

Thus, from the data available to date, it appears that in patients with a unilateral FTMH, the overall risk to a normal fellow eye without a PVD is in the region of 10–20%.
systemic vascular disease, and mechanical forces due to fluid motion and countercurrents in the premacular bursa during ocular movements. However, it is now generally accepted that idiopathic FTMH are caused by vitreofoveal traction. This is consistent with the presence of radial striae in the majority of cases during the early stages, the presence and progression of the yellow spot and ring during stage 1, a relatively high incidence of PVD following the development of FTMH, and the negligible risk of hole formation in eyes with a pre-existing PVD. Although some authors have suggested that anterior vitreofoveal traction occurs as a result of shrinkage of vitreous collagen fibres extending from the fovea to the anterior vitreous, it seems unlikely that this mechanism accounts for the majority of cases, because anterior displacement of the foveal rim forward of the retinal surface is rarely seen and where it does occur, it is associated with an incomplete PVD at the macula and is termed vitreomacular traction syndrome.

Gass and Guyer and colleagues have suggested that FTMHs arise from local tangential vitreofoveal traction due to either shrinkage of the prefoveal vitreous cortex caused by cellular remodelling or by contraction of a thin glial membrane on the retinal surface. The presence of a glial membrane has been emphasised by Gass who has proposed that in the “can opener” stage 2 lesion, a glial membrane covers the surface of an “occult” hole and progression of the can opener represents an extending dehiscence in the membrane itself, finally resulting in a free “pseudo-operculum”, comprising exclusively glial tissue, suspended on the vitreous cortex after vitreofoveal separation has occurred. The position of a “pseudo-operculum” suspended on the vitreous cortex anterior to the retinal plane is a consequence of the anterior vectoral component of a tangential force at the surface of the fovea.

More recently, Gass has emphasised the importance of the foveal Muller cell “cone”, originally described by Yamada and Hogan et al in histological studies of the normal human foveola (Fig 1). These studies showed the foveola to be composed of an inverted cone of Muller glia with a truncated apex up to the external limiting membrane (ELM). Between the apex and the ELM were radially oriented inner cone segments radiating towards the beginning of the outer nuclear layer of cone nuclei. The base of the cone formed the umbo and extended into the clivus in the perifoveolar region. The internal limiting membrane (ILM) lining the base of the cone was extremely thin (10–20 nm) compared with the peripheral fovea. The sides of the cone were apposed to radiating inner segments centrally and cone nuclei in the outer nuclear layer more peripherally towards the perifoveolar region.

Gass has suggested that the Muller cell cone has three important roles in idiopathic FTMH formation. (1) The glia contain concentrated superficial xanthophyll which migrates centrifugally during the formation of a FTMH and may be seen biomicroscopically as a yellow spot or ring. The presence of xanthophyll with opercula supports this hypothesis. (2) The Muller cone provides structural support for the radiating inner cone segments at the foveola and its disruption may lead to damage and atrophy of the cone cells in this area. (3) The Muller cells within the cone invade the prefoveal vitreous cortex and initiate cellular remodelling and contraction, resulting in tangential forces on the fovea, centrifugal migration of photoreceptors and xanthophyll, further disruption of the Muller cell cone, and eventually an umbo dehiscence. Furthermore, a potential cleavage plane may exist between the truncated apex of the cone and the cone elements at the umbo which may result in schitic changes at the foveola during hole formation.

Although previous histological data from light and electron microscopic analysis of prefoveal vitreous cortex, removed at the time of surgery for impending holes, have confirmed the presence of glial cells at this early stage of hole development, it remains unclear whether these glia initiate foveolar traction by cortical vitreous remodelling or whether they represent an attempted healing response to mechanically induced damage at the fovea due to vitreous traction. A number of observations indicate that epiretinal glial proliferation at the fovea occurs commonly even in apparently normal asymptomatic eyes: (1) Foons has demonstrated at post mortem the presence of a preretinal glial membrane in up to 30% of apparently normal eyes without PVD where no retinal distortion is present; (2) the majority of eyes (70%) with holes do not appear to have significant visible membrane around the edge of the hole; (3) only about 50% of holes are found to have glial proliferation at surgery, and in the vast majority this is of a very friable and nebulous nature rather than the typical confluent ERM found in macular pucker.

Histopathological studies on the ultrastructure of stage 3 macular hole opercula have provided further clues to the pathophysiological mechanisms in FTMH formation. Overall, all opercula (100%) studied so far have been found to contain Muller cells and/or fibrous astrocytes, 61–100% have had identifiable ILM fragments and about 40–50% have contained cone photoreceptors ranging from a few scattered cones to those with densely packed cone photoreceptors.

It is difficult on histological grounds to determine whether glial cells within an operculum are avulsed epiretinal glia within a membrane (that is, a pseudo-operculum),...
avulsed inner retinal glia (that is, a true operculum), or both. However, the presence of fragments of internal limiting membrane in some opercula (61–100%) indicates that a significant number of opercula containing only glia contain avulsed glial tissue from the inner fovea and are also “true opercula”. The lack of identifiable ILM in some opercula suggests that these may represent avulsed epiretinal glia rather than inner retinal glia and that in these cases “in situ” disruption of the Muller cell cone may indeed be sufficient to cause an umbo dehiscence.

The variation in cone photoreceptor density in opercula (40–50% contain photoreceptors) probably reflects the amount of foveal tissue avulsed during hole formation. In fact, clinicopathological correlation on a small number of opercula from stage 3 holes, excised during vitrectomy, has shown that the anatomical success rate following surgery is lower in cases with opercula containing a high cone density. This may reflect the larger tissue defect in these cases, where effective postoperative glial repair is less likely to occur. However, it is difficult to draw firm conclusions from these data because of the small numbers of cases involved and clearly further clinicopathological correlations of macular hole opercula would be valuable but difficult owing to the small size of the opercula. Histological postmortem studies on surgically closed FTMH have also shown that the residual foveal defect sealed or “plugged” by reparative glia after successful surgery may range from 16 to 250 µm consistent with a spectrum of pathology.

**Optical coherence tomography (OCT) and recent hypotheses of the pathogenesis of FTMH formation**

Recent studies of the early stages of FTMH using OCT have shown that vitreomacular separation may actually occur around the posterior pole before hole formation rather than after hole formation as suggested by Gass. These observations have suggested that an incomplete posterior pole vitreous cortical separation occurs with residual tethering at the fovea and optic disc, and assumes...
a “trampoline” configuration (Figs 2–4). 76–79 This anatomical configuration may be seen in stage 1 lesions where no vitreous separation can be detected clinically by biomicroscopy and would be consistent with the observations on postmortem eyes, using electron microscopy, of firm vitreoretinal adhesions at the fovea which are not present elsewhere. 79–80 Mechanical forces transmitted through the vitreous with eye movements and possibly contraction of the vitreous face between the fovea and the disc and between the fovea and the residual peripheral extramacular temporal attachment, would result in an oblique vector force with both anterior and tangential vectorial components, 81 leading to avulsion of foveal tissue and complete posterior pole vitreous separation.

As further traction occurs, a full thickness tear is seen through the fovea resulting in the formation of a stage 2 FTMH with focal tethering of the posterior vitreous cortex to the operculum. Eventually, the operculum is completely avulsed from the fovea resulting in a stage 3 FTMH characterised by complete vitreomacular separation and release of the tractional forces on the fovea. Thus the operculum would come to lie anterior to the preretinal plane and this is the earliest time at which vitreous separation over the macula can be detected with biomicroscopy.

In a recent OCT study Gaudric et al. 82 confirmed the “trampoline” configuration of the vitreous cortex in the majority of eyes with FTMH. They also demonstrated that some impending holes are characterised by foveal cyst formation, with the presence of a cystic cavity beneath the elevated retina and retinal tissue beneath the cystic space. The potential cleavage plane in the foveola between the inner retinal Muller glia and the laterally displaced cone inner segments was confirmed. They concluded that in a significant number of holes, localized vitreofveal traction results in the formation of a foveal cyst, through the cleavage plane, which later becomes deroofed. The avulsed roof, comprising glial cells only, would form a glial operculum, while the uncovered floor of the cyst, comprising cone nuclei, would degenerate resulting in a FTMH. These findings indicate that FTMH may arise from different precursor lesions, as a full thickness foveal detachment, as described by Gass, or as a foveal cyst. It is possible to speculate that in FTMH arising from cysts, the operculum would comprise glia only, while in those preceded by a cyst, the operculum would contain some photoreceptor elements.

The OCT findings suggest that FTMHs develop in a situation where there is failure of normal age related separation of the vitreous cortex from the posterior pole as a result of an abnormally tenacious attachment to the fovea. The residual attachment at the foveal centre, in the trampoline configuration, may act as a focal point where mechanical forces are transmitted from the vitreous to the foveolar surface leading to foveal traction. Clearly, further studies are required to confirm these findings and to determine the validity of these concepts; in particular, detailed natural history studies correlating the clinical progression of FTMHs with the OCT findings. Clinicopathological correlation between biomicroscopic and OCT findings and the cone density in opercula may shed further light on the precise mechanisms leading to hole formation. Such studies will help to define the risk characteristics for progression in early lesions and risk factors for visual outcome after surgery.

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